VAN NOSTRAND'S

ENGINEERING MAGAZINE.

NO. CLXXVIII.—OCTOBER, 1883.—VOL. XXIX.

ON THE DEFENSE OF HARBORS BY SUBMARINE MINES.

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From the "Journal of the Royal United Service Institution."

It is with the greatest diffidence that I venture to read a paper this afternoon on any component part of that vast and comparatively undeveloped subject of torpedo warfare, and most certainly should never have offered so to do, had I not received a very flattering and encouraging request from the Council of this Institution to prepare a similar paper at the end of 1879, when I was on the eve of departure for China, and therefore unable to comply, and had I not also received valuable assistance from many able authorities on torpedo matters.

The magnitude of my subject, and the short space of time at my disposal, will only allow of a mere cursory glance at most of the details of harbor defense, and but little more at those of submarine defense, which really constitutes the main feature of my paper, and it is on these latter details that I look for some clear light to be thrown by the discussion which I hope may be invoked by to-day's work.

I will here mention that, with the exception of Captain Long's lecture on "Naval Blockade," and the one on "Torpedo Boats" by Mr. Donaldson, there has been no paper read at this Institution on any of the various branches of torpedo warfare since 1875, and only some half-a-dozen since its foundation.

The various items constituting a system of defense for harbors, river mouths, &c., may be broadly classified as follows:

1. Fortifications.
2. Vessels of war.
3. Guard and torpedo boats.
4. Submarine defense.

The sheer impossibility of preparing a paper which should contain an adequate treatment of each of these items, in a manner worthy to be presented to a scientific naval and military audience such as are usually gathered here, decided me not to even attempt a partial diagnosis of the first three of those items, but to devote my paper to the last but not least important of them, namely, "*Submarine defense.*"

I think it best to mention here that, on the completion of my paper, I shall, by the kind permission of Captain McEvoy, explain the manipulation of two of his many inventions, being his "Single Main System of Torpedo Defense," and his "Submarine Detector." The inventor is a gentleman who has devoted the greater part of his life to the invention and improvement of torpedos and other military matters, and who is well known to many of you.

In discussing the subject of submarine defense, it will be best for the sake of greater clearness, to divide it into its

constituent parts; these may be defined as—

A. *Systems of fixed mines.*

B. *Locomotive torpedo submarine boats.*

C. *Submarine boats.*

D. *Passive obstructions.*

In dealing with these points, I prefer to leave that one prefixed (A) until the last, constituting, as it does, the main feature of submarine defense, and therefore requiring special and close attention.

I will then first treat of—

B. *Locomotive torpedo submarine boats.*—This part may be further divided into *controllable* and *uncontrollable* boats; the former class being represented by the Lay torpedo-boat, the latter by the Whitehead or fish torpedo-boat.

These representative submarine weapons being well known, and time pressing, I will not attempt to describe them, nor enter into the question of their merits and demerits. With regard to the Lay torpedo-boat, I have authority for stating that it has been of late considerably improved, its speed having been greatly augmented, and its manipulation much simplified. I believe it is generally conceded that a *controllable* locomotive submarine torpedo-boat is the form best suited for the requirements of harbor defense.

Then I come to the question of—

C. *Submarine boats.*—Up to the present time no practical adaptation of this mode of progression under the sea has been wrought out, though I am told of a submarine boat now under trial in Sweden that is to be a perfect success. It is to Russia that we should look for a solution of this difficult problem; for there the matter has of late years received the closest attention, but as yet without any definite practical result. I confess to having very little faith in submarine boats ever being brought to that state of practical efficiency which is needed for the work they are intended to perform in connection with torpedo *defense*, such as the destruction of fixed mines and their cables, &c., owing to the insuperable difficulty of piercing the intense gloom of the surrounding matter, when proceeding beneath the surface of the sea. Of course if, by the aid of electricity or other power, this difficulty of vision be overcome, and also that of the motor for these craft to such an extent that it becomes a feasible and safe matter to start from a ship in the offing in one of these subaqueous craft, pick up the harbor entrance, and moving about at a considerable depth, cut the *steel-wire* mooring ropes and *armored* branch cables of the submarine fixed mines, then these craft will most certainly demand the bestowal of far more attention than I think they deserve as at present constructed and manœuvred. This brings me to question—

D. *Passive obstructions.*—This mode of barring a channel or other entrance, either by the sinking of weighted ships, piles, frames, or other methods, will no doubt prove extremely useful in many instances. The action and construction of such obstructions are, I consider, sufficiently well understood as not to require any special attention in this paper.

I must here explain that the subordinate positions I have *seemingly* assigned to the foregoing particulars of submarine defense, is due to the short space of time apportioned to my paper, and not to any want of belief on my part of their *great value* under *special* circumstances.

I will now proceed with the important question of—

A. *Systems of fixed mines.*—By a system of fixed mines I intend to be understood all methods of submarine defense necessitating the employment of fixed or anchored mines, and such I consider to form the backbone and most important factor of any scheme of coast defense that may be devised; the question (A) may then be resolved into the minor ones of—

1. *Systems of self-acting fixed mines.*

2. *Systems of dependent electrical fixed mines.*

I will first treat of the systems considered under section (1): these may be subdivided into *electrical* self-acting and *mechanical* self-acting fixed mines—the former including those whose firing agent is electricity—the latter those whose firing agent is mechanism.

The special application of a system of self-acting fixed mines for coast defense purposes is that of defending certain isolated and other portions of the defensive ground, where, for economy's sake, or for some other cause, it is not necessary to advert to the dependent form of defense.

The one great objection to any system of self-acting fixed mines is that the ground protected by them becomes a source of danger alike to friend and foe, and also the danger that has hitherto attended the planting and picking up of such mines; as regards this latter source of danger, so strongly condemned by Major Parnell in his lecture on "Coast Fortifications," where he says, "As for mechanical mines, they are hardly worth the mentioning, and are sources of danger to their employers rather than to those they are employed against," Captain McEvoy has, by some simple yet very practical improvements, I venture to assert, almost entirely expunged this objection. Were it not for the question of economy—the bugbear of all schemes of defense—I should advocate the entire *disuse* of self-acting fixed mines, and wholly depend on the dependent electrical fixed mines for coast defense, but as this economy question cannot be ignored, then this branch of submarine defense requires the most careful consideration.

Dealing first with the question of electrical self-acting fixed mines, we notice that but very few attempts have been made to devise anything practical in this line, for the reason that where any system of electrical mine contains within itself the power of firing its fuse, an inherent risk of premature explosion must always, in a more or less degree, be present, and this source of danger exists, though in the latter in a minor degree, in the only two inventions of this kind that claim special notice, viz., the Hertz and the McEvoy systems of electrical self-acting fixed mines. The former has been in use for some considerable time, especially by German torpedoists, and it was employed by the Russians on the Danube in 1877, when it was on one occasion successful, whilst the McEvoy system has been only lately perfected.

The Hertz system may be roughly described to consist of a mine case, on the head of which are screwed five lead cylinders; inside of these are placed five glass tubes containing chlorate of potash; beneath the lead cylinders, on the inside of the mine, are affixed five dry batteries; on either of the lead cylinders being struck by a passing vessel the glass tube is broken, and thus the battery rendered active and the mine exploded. This form of self-acting fixed mine I consider to be a most dangerous one, either to plant or to pick up; the latter fact I can vouch for, having had the unpleasant and dangerous task of clearing a part of the Danube in which some Hertz mines had been laid by the Russians. Its uncertainty I can also testify to, having seen one of the Hertz mines that had been torn from its moorings by the screw of a passing Turkish monitor, and drifted on to the bank of the river without exploding; one of its lead cylinders was considerably bent, but not sufficiently so to smash its glass tube. I was also once unwittingly anchored for some time over one of these mines, whilst on board the turret vessel "Hifsi Rahman," in company with the late Captain Manthorp, R. N., which, we subsequently learnt from the Russian officers, they had attempted to explode by every means in their power, without, I am happy to say, succeeding.

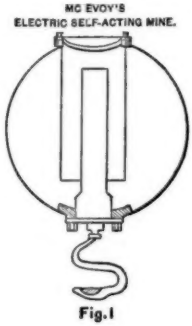


Fig. 1

Captain McEvoy's electrical self-acting fixed mine, a section of which is shown in Fig. 1, consists of a small battery and a circuit closer placed within the mine case, also ingenious electrical arrangements for the prevention of premature explosions; as will be seen, he depends for the action of his mine on the contact of a hostile ship with the actual mine itself, and not with any particular excrescence. Captain McEvoy has not permitted me to exhibit this clever invention here; but I may mention that General Abbott, of the United States Torpedo Department, has ordered one of these mines for trial in America, as he considers it to be the most perfect one of its kind.

To eradicate the inherent danger I have before spoken of that exists in the ordinary electrical self-acting fixed mines, a system known by the name of the "sunken battery" was introduced. Here a set of five or more buoyant fixed mines containing circuit closers are connected with a voltaic battery, which is inclosed in a strong metal box, and sunk near its mines. This is an old idea, but it has hitherto failed, owing to the difficulty of obtaining a reliable battery; but with the present efficient state of the Leclanché, this difficulty has been overcome. I will now proceed with—

Mechanical self-acting fixed mines.—Of these there are numerous and varied kinds, principally devised by the Confederates, and of them the "Singer" falling weight invention has been more extensively used, and oftener successful, than any other species. Now, this form of mine Captain McEvoy has taken in hand of late, and, I venture to say, so improved it, that this mechanical self-acting fixed mine may now be considered as capable of supplying the want that has been long felt in submarine defense, namely, a mechanical self-acting mine that can be moored with perfect safety, whose action is certain. and that can be recovered with the minimum amount of risk. The original falling weight has been altered in shape and manner of resting on the head of the mine case. This new form of weight is prevented from falling off until a mine has been placed in position by a very simple mechanical contrivance; and to enable the recovery of one to be effected in perfect safety, another arrangement has been introduced, whereby, though the weight may be knocked off, yet the mine will not be fired. I am not at present at liberty to divulge anything further in connection with this newly improved mine, as it has not been patented. If the proper precautions be observed when carrying out the work of recovering self-acting fixed mines, such as waiting for smooth and dead low water, employing an experienced and careful boat's crew, and also using the submarine detector, there should be no danger or difficulty whatever in picking up the "McEvoy improved Singer self-acting mine;" and this I aver with the experience I possess of such work with *unknown* self-acting mines.

I will now make some remarks on the subject of "Dumb Mines," or "Dummies." The reason originally advanced for the employment of such things was to increase the difficulties and tediousness attendant on any attempt that might be made by an enemy to clear a space protected by fixed submarine mines. Now, this should most decidedly be the only duty delegated to dumb mines, instead of which there seems to be a most pernicious tendency at the present time towards the use of dummies in the place of actual mines, and to trusting the safety of a harbor entirely to moral in the place of real defense. There is, no doubt, a possibility of utilizing the moral effect of submarine defense for the purpose of deterring the attack of a hostile fleet, but to depend on the safety of any place by such means alone, is, in my opinion, radically wrong, and is opposed to all the principles of real defensive warfare. I think it is hardly necessary to mention here, that were it England's misfortune to be drawn into a European war, then any of her opponents' harbors thus morally protected would soon fall into the hands of her fleet. This concludes my remarks on systems of self-acting fixed mines, the details of which want of time prevents me from more fully discussing; not the less, I must impress on torpedoists in general, the great importance that attaches to this branch of submarine defense; for, owing to the necessity of economy, electrical dependent fixed mines will be used as sparingly as is consistent in harbor defense, and their proper places supplied by the cheap self-acting mines, or possibly by the still cheaper dummy.

I now proceed to the study of section (2)—

Systems of dependent electrical fixed mines.—Of these, under certain circumstances, four different species have hitherto been employed, namely, the "ground" and "buoyant" fixed mines, and these combined with their circuit closers in separate buoyant cases.

The advantages claimed for any *ground* system of fixed mines are—the practicability of employing heavy charges, no liability to damage by the contact of passing vessels, and their certainty of position always secured.

Now, though none of these advantages

may be possessed by the buoyant system of fixed mines—unless it be the latter one—yet, owing to the uncertain and complicated operations attendant on the work of exploding a ground fixed mine at the exact instant of the hostile ship being within its destructive area, I prefer to depend entirely on the buoyant system for the protection of harbors by submarine defense; and I consider it most unadvisable and generally useless to employ the ground system of fixed mines. In the case of a mine charged with 500 lbs. of gun-cotton and moored at its most effective depth, the radius of its destructive effect is, even with that large charge, only some 25 feet.

In the event of unforeseen circumstances rendering it impossible to use the system of buoyant mines, then I would rather trust to moral effect and self-acting mines than go to the trouble and expense of laying down a system of ground mines, necessitating the employment of any known method of observation firing, which at best can only be utilized at certain times.

I use the expression "known," for Captain Watkins, in his lecture on "Rangefinders," at this Institution, mentioned the invention of a position-finder, which he stated was capable of automatically connecting up and exploding ground mines within less than 9 feet of vessels moving at a speed of from 8 to 9 knots per hour. But, notwithstanding this invention, I cannot see any necessity that could arise where aught but the buoyant system need ever be employed, and thus I propose to do away entirely with the ground system of dependent electrical fixed mines, and also with those combinations of mines and separate circuit closer cases, and by so doing to adhere to one of the fundamental principles of torpedo warfare in all its branches, viz., *simplicity*, a principle, I venture to say, far too often overlooked.

My preference for the sole adoption of simple buoyant fixed mines in any system of submarine defense by dependent mines is based on the following grounds:

I consider *firing by contact* to be the only truly practical and effective mode of carrying out submarine warfare, possessing, as it does, the needful elements of success for the destruction of a vessel, namely, the delivery of the whole force of the explosion, at the right instant, and in the weakest part; and, therefore, I regard buoyant fixed mines as wholly and solely contact-fired mines. Then, following out this reasoning, I fix the maximum charge of such mines at 100 lbs. of gun-cotton or other explosive compound, which amount is some 40 lbs. in excess of the charge considered necessary for the contact-fired Woolwich fish torpedo.

By thus limiting the charge and making the mines contact-fired ones, I obtain for the buoyant system the following advantages: greater certainty of destructive effect; less expense of material; and simplicity, in placing in position, as it is unnecessary to exactly plant each mine in the actual position assigned to it, as would be the case where any system of ground dependent electrical fixed mines is employed.

A buoyant mine such as I have described is shown in Fig. 2.

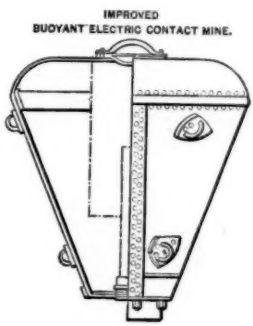


Fig.2

Then comes the question of "mooring" buoyant mines. This has hitherto been considered a matter of great difficulty, and no doubt, under certain exceptional circumstances, would prove a troublesome business. Most of the difficulties hitherto present in effectively mooring such a mine have been to a considerable extent overcome by the employment of a steel wire mooring rope, which prevents it spinning around, and which would be found strong and pliant enough to ensure its being retained in its proper position under ordinary circumstances, the weight of the anchor having been carefully calculated according to the position

of the mines, depth of water, flow of tide, etc.

In exceptional cases a mode of mooring such as is shown at Fig. 3 might be adopted with advantage.

There still remains to be devised some practical method of retaining a buoyant mine at its normal depth in places where the rise and fall of tide is very great. Mooring groups of mines at different depths, increasing with their distance from the base of operations, rectifies to some extent this fault, but necessitates a considerable increase in the number of mines, and therefore in the cost of the defense.

Another point in connection with the use of buoyant mines is the necessity of constructing them in such manner that they be rendered impervious to the constant ramming they would most probably re-

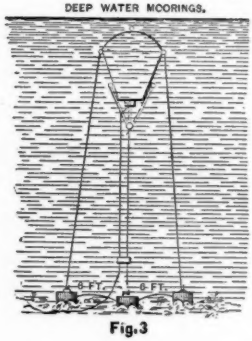


Fig. 3

ceive from the passage of friendly vessels if planted at the entrance of an important harbor; and the chances of accidents occurring from this cause must be carefully guarded against by forming them of watertight compartments filled with cork, or some other method of rendering them unsinkable.

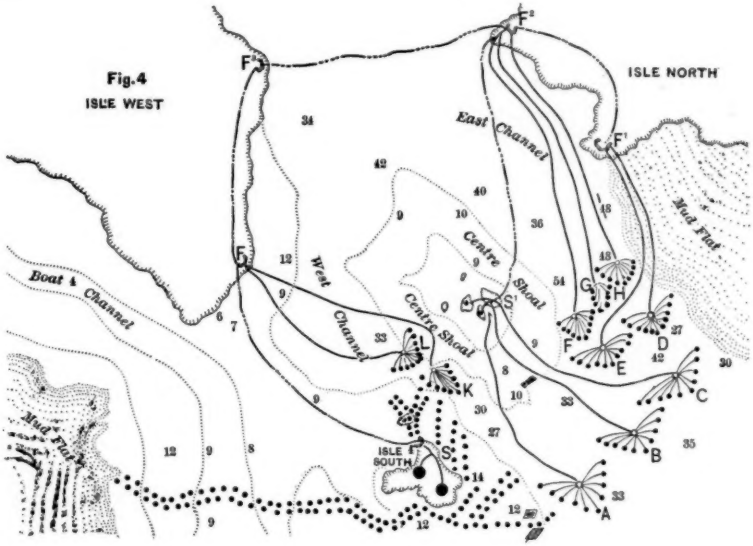
Having thus briefly discussed the various items of submarine defense, I will now treat the subject in its entirety; and to enable me to do this clearly, and, I hope, effectively, I have prepared rough plans of a submarine defense of a river entrance and open seaport, both of which places will be probably recognized and familiar to many of my audience. I have preferred this method to the one usually adopted of creating a plan to suit the particular system of submarine defense under discussion.

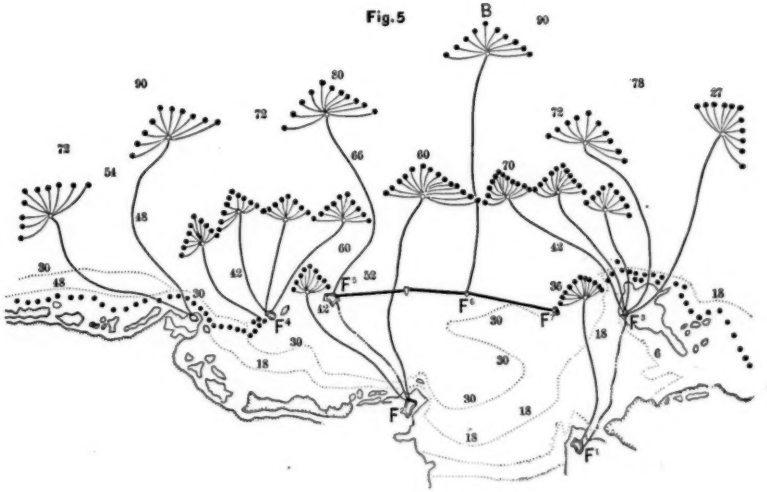
Fig. 4 represents the plan of a system of submarine defense for what I term a "close" harbor, while Fig. 5 shows similarly the defense of what I term an open harbor. The former is, of course, more adapted to such a mode of defense than the latter one.

I will first take the case of the close harbor, Fig. 4. To the North is situated a large island named Isle North, which it is impossible to circumvent by any but very light draught boats, and therefore very simply secured from rear attack. Flanking it is an extensive mud flat. To the West is another large island, Isle West, also secure from rear attack. Between these two islands flows a deep-water main channel, which is divided into East and West channels by the center shoal and S′ islands. The East channel ranges from three-quarters to a mile in breadth, the West channel from a quarter to three-quarters of a mile. Between the Southwest mud flat and Isle West flows a shallow boat-channel about a mile in breadth at its widest part, but narrowing and shallowing considerably as it runs to the North. The average depth in the East channel is about 40 feet—ranging from 5 to 8 fathoms; in the West channel the mean depth is about 33 feet, whilst the depth of the shoal water to the Southwest is from 13 to 3 feet, and on the center shoal it is some 10 feet. The rise and fall of tide is about 4 feet, and flows at the rate of from 2 to 4 knots per hour. The nature of the bottom is mud.

In planning the submarine defense of any harbor the points to be taken into consideration are—the object and importance of such defense, the assistance afforded by its natural formation and land defenses, and the question of expense. And, going further into details, there would have to be considered—the number, position, formation, and class of the dependent electrical and self-acting fixed mines; also the question of the employment of locomotive submarine torpedo-boats.

In the particular case under review, the river, of which a sketch of the entrance is shown, leads to a most important town, possessing an arsenal and dockyard; and therefore the object of





its defenses, both land and submarine, would be the complete prevention of capture or of an effective blockade being established. Its natural formation lends great assistance to a work of defense, as the plan shows; and this is still further strengthened by the fact that a similar formation of narrow channels and high land is found about 10 miles further up the river, so that really the defense here treated of would only be considered as an advanced work.

First, as to the "fixed" mines themselves. The system of manipulating the dependent electrical fixed mines in this case, and also in that of the open harbor,

would be the "McEvoy's single main system," Fig. 7; and, taking into consideration the depth of water, rise and flow of tide, "buoyant" fixed mines of maximum power would be used, that is, those containing a charge of 100 lbs. of some explosive compound. The "self-acting" fixed mines would be McEvoy's improved Singer mine, containing only 50-lb. charges; and single moorings would be employed for both the dependeut electrical and self-acting fixed mines.

Then as to their formation. By this I mean the shape or form in which the mines composing each group should be planted so as to reap the greatest advantages, such as—spreading over the largest space with greatest probability of success; simplicity in planting them and of laying out their branch cables; less chance of discovery by dragging on the part of the enemy. Now, considering carefully these points, I have preferred to adopt in the place of either circular, single line, or échelon, a triangular formation, whereby I contend the foregoing advantages are obtained in a high degree. In Fig. 6 I have compared these four methods. The mines here are supposed to be planted at a distance of 600 feet apart, the two lines in the échelon case being 900 feet distant, which is the greatest space allowable. Then calculating the spreading area of each formation to be its length multiplied by its depth, I roughly get, taking s as the area for the triangle formation $\frac{1}{2}\,s$ for the circular area, $\frac{1}{3}\,s$ for the échelon area, and $\frac{1}{1000}\,s$ for the single line area.

Then for the probability of success. A ship steaming on to a group of mines of the triangle formation would be almost sure to strike one or other of them, which would not be so certain in either of the other formations, unless it be the circular one.

For simplicity in planting, &c., the single line is of course the simplest, but next to it comes the triangle form.

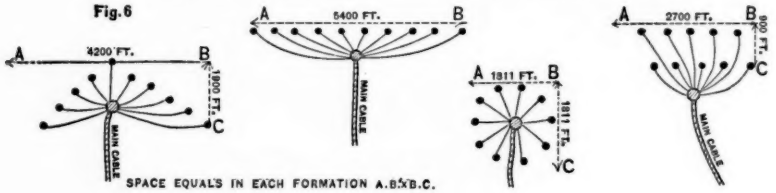
Then as to the chances of discovery. Two or three mines of a triangle-shaped group being picked up by dragging would not afford as sure an indication of the position of the remainder as would be the case were either of the other formations resorted to.

Then as regards the number and position of fixed mines. One of the principles of submarine defense is, the prevention of serious damage to the first line of fortifications by the gun-fire of the enemy, and the forcing and retaining as long as possible under a powerful cross-fire the attacking vessels when forcing an entrance. To effect this the outer groups are planted as shown at A, B, and C, in Fig. 4. It would have been still more effective had I chosen to fortify Isle South, and consider that as the first line of land defense; but this would necessitate a great increase in the material, and consequently in the expense of the defense, so I have only treated this isle as a look-out station, and as a place capable of affording a refuge for the guard vessels and torpedo-boats of the defense. The station itself at S would be a bombproof, covered earthwork, carrying a few light guns, electric lights, &c., for the purposes of guarding and watching the outer groups of mines. And station S would be connected with fort F by the submarine telegraph cable C′, and by this cable its mines would also be fired when requisite, to render the place useless to the enemy.

Next comes the question of the defense of the different channels. The east channel, I calculate, would require at least 50 dependent electrical fixed mines, those in each group being placed 300 feet

GROUP FORMATIONS FOR FIXED SUBMARINE MINES

Fig. 6



SPACE EQUALS IN EACH FORMATION A.B.B.C.

apart. The west channel might of course be effectually and simply blocked by planting it with self-acting fixed mines, but I have preferred to utilize this passage as a mode of egress and ingress for the vessels and boats of the defense whilst carrying out their special duties. The boat channel is rendered inaccessible by self-acting fixed mines being laid down in the shoal water to the south-west. A boom obstruction, combined with some aqueous batteries for the use of locomotive submarine torpedo-boats.

One battery might be placed to the south of Isle South, as at L, and its torpedoes manipulated from station S; another one, L′, off the work at S′, and controlled therefrom. The Germans are now experimenting with sunken batteries, containing six Whitehead uncontrollable torpedo-boats, starting them by some application of electricity; but the practical

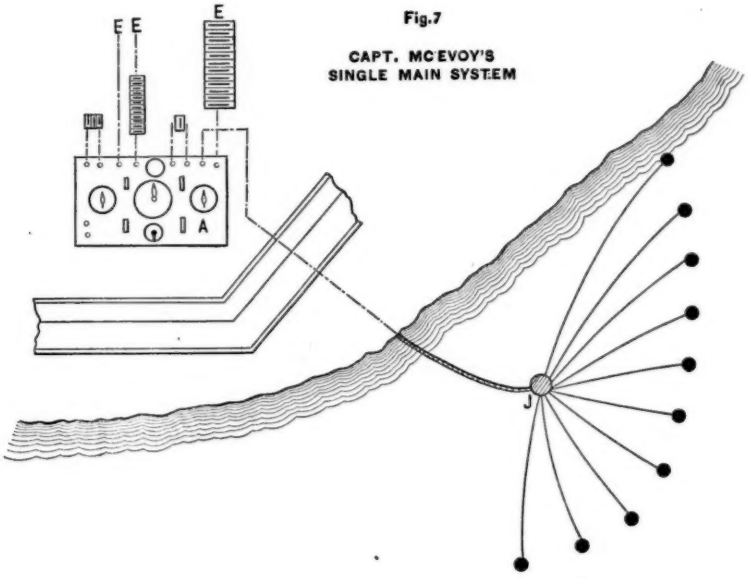


Fig.7

CAPT. MC EVOY'S SINGLE MAIN SYSTEM

few self-acting mines, would be prepared in readiness to further block the channel at its narrowest part, on the outer defenses being forced.

The main and telegraph submarine cables, of which there are thirteen, are so laid that no crossing of them occurs, and with due regard to the economy of the defense.

The shoal water round about Isle South is planted with self-acting fixed mines. These might with advantage be to a great extent supplanted by the dependent electrical system of fixed mines with 50-lb. charges, and controlled from station S; but such would no doubt be considered too expensive.

Then we come to the subject of subknowledge as regards the best mode of operating these subaqueous weapons has yet to be acquired, so I will not venture to further discuss them.

Having thus somewhat meagrely gone into the matter of the submarine defense of what I term a "close" harbor, I will now proceed to discuss the question of a similar mode of defense in the case of an "open" harbor, a rough sketch of which is shown in Fig. 5.

The actual harbor is comprised between forts F‘ and F, and is formed by means of a breakwater; the depth of water off the breakwater entrances, and at the outer (B) group of mines, ranges from 6 to 13 fathoms. The 5, 3, and 1 fathom lines are shown by the dotted lines. The

strength of the current varies from 2 to 4 knots, and in this case a considerable rise and fall of water is met with, namely, some 20 feet at spring, and 13 feet at neap tide.

The nature of the dependent electrical fixed mines used would be buoyant ones of maximum power, and they would be specially moored somewhat after the manner shown in Fig. 3. The self-acting fixed mines would be similar to those used in the defense of the close harbor.

The distance extended by the outer line of submarine defense is upwards of 6 miles, and the groups of mines composing it are laid at some two miles' distance from the first line of fortifications. By the disposition of the dependent fixed mines, as shown in my plan, I hope to obtain what is the *sine quâ non* of such work, namely,—a maximum power of defense with a minimum of cost and of complication; and I cannot believe the capture of any harbor known to be so strongly fortified and supported by so powerful a submarine defense would ever be attempted, and thus the grand object of such a combination would be obtained, which is, the rendering of a port actually impregnable. The bombardment of the town and arsenals would have to be performed at a distance of 3 miles, and from seawards.

The dependent mines in this case are all planted as it were in the open sea, and thus any attempts made to damage or destroy them must be depended on the state of the weather, and so would not be of so frequent occurrence, or stand so much chance of success, as would be the case in connection with a close harbor, where such attempts would possess an important element of success, namely, "smooth water."

The coast about this port is an extremely rocky and dangerous one, and therefore would not require a large number of self-acting mines as a flanking defense; also the fact of their having to be moored on a sea coast would militate to some extent against their use, owing to the possibility of some of the mines breaking adrift in heavy weather. I have shown in the plan a few of these mines planted along the coast, but the actual position and number of them would have to be determined by those more thoroughly acquainted with the peculiar exigencies of the situation.

This will conclude my necessarily very few brief remarks on the subject of a submarine defense of a close and open harbor, such as I have exemplified, and the only excuse I can offer for such a concise treatment of an important subject is the vastness of the field I have attempted to cover in one short paper.

Until within the last few years, and even I believe at the present time, torpedo warfare has been looked on as something uncanny, and too terrible. Now, the primary object of submarine defense is the safeguard of a harbor against the attack of a hostile fleet, and I maintain, that in the event of an enemy's ship being sunk in any attempt to force a harbor so protected, those responsible for such service being carried out should be held accountable for any loss of life ensuing from such a catastrophe, and not those responsible for such defensive means being resorted to. As a rule, it will be generally known whether any particular harbor is studded with fixed submarine mines or not; and should the slightest doubt whatever exist as to that fact, it would in my opinion be a most foolhardy and reprehensible act on the part of any one to attempt to enter such a port.

The popular delusion as to the resultant effect of an explosion of a submarine mine in contact with a vessel-of-war still, I believe, exists, which is, that the ship is blown into the air into small pieces, with the total loss of her crew, while the actual effect with ships as at present constructed would be at the most the gradual sinking of the ship caused by a large hole being made in her double bottom, and with but few casualities to the crew, they having ample time to get clear off in her boats.

Surely this cannot be considered as uncanny, nor yet one iota as terrible as those constant and dreadful bombardments between forts and ships usually ending so seriously for the crews, which have hitherto been so common a feature of maritime warfare; but which the general adoption of submarine defense will to a great extent lessen, and thus the uncanny and too terrible torpedo may under such circumstances be looked upon as really a *life-saving* weapon.

Notwithstanding the imperfection of the systems of submarine defense used during the American Civil War, yet even then we find Admiral Dahlgreen writing: "I believe torpedoes to constitute the most formidable of the difficulties in the way to Charleston." But though some twenty years have elapsed since those words were written, and during this period submarine defensive material has been vastly and generally improved, and that in actual war submarine defense has been proved to be of immense value, yet we find Major Parnell writing: "Submarine mines do not, however, form material obstacles, and it is probable that their value is chiefly of a moral nature."

And yet another officer, Captain Barrington in his work entitled "England on the Defensive," though the author to some extent appreciates the value of submarine defense, says: "But torpedoes can only destroy or cripple the first line of attack, and when they have acted, the enemy can advance without further hindrance." Also Commander Barber, U. S. N., in an article on the progress of torpedo warfare, though he looks on fixed submarine mines as of immense utility as auxiliaries to other systems of defense, yet distrusts them to a great extent, on the belief that countermining and cable cutting will often prove successful; and also the general tenor of the remarks made *á propos* of the employment of torpedoes in the discussions here and elsewhere, is to the effect that torpedo warfare cannot yet be safely relied on, and therefore need not be seriously considered in matters of attack and defense. Now all this is, I venture to say, a great and radical misconception of the real value of submarine warfare, which should most certainly be eradicated at once from the minds of all naval and military men —especially of ours—who will, in the event of war, find the at present slighted and ignored torpedo of infinite value for defensive purposes, and I fear a terrible bugbear in all naval operations.

In the event of an organized invasion of England, which to judge from the numerous articles and letters published of late from the pens of some of the ablest of our naval and military officers, would seem to be looming in the immediate future, we should have to depend for the safeguard of our numerous harbors, ports, inlets, &c., (which number, I believe, some 280), almost entirely on submarine defense—at any rate at the outset—that being the cheapest and most ready to hand of any defensive means; and this applies not only to England, but to all countries possessing any extent of sea coast.

One of the principal objects of an invading force would be an immediate descent on some known unprotected part of our coast, and there effect a landing; but if all the numerous places that must exist in a more or less unprotected state, when land defenses and the presence of a fleet only are relied upon, possess a means of submarine defense, and a trained body of men to manipulate it, then the enemy would first have to wholly or partially destroy this submarine defense, before proceeding to the work of landing, thus occasioning at least a considerable delay, and affording time for our ships to arrive, with the probable result of the failure of the invading force at that particular attempt, and possibly the utter collapse of the expedition.

I trust no misconception may arise from anything I have said as to the value and importance of our Navy; but what I have intended to express is the absolute necessity of submarine defense to enable our splendid Navy being fully utilized, and affording it full opportunity to carry out the multifarious and onerous duties assigned to our ships at the present day, and this with perfect immunity to us from invasion.

Then, again, the vast economy of submarine defense entitles it, on that ground alone, to far greater importance and attention being paid to it than is usually the case; and, as a proof of this economy, I will mention that employing the "McEvoy single main system," Fig. 7, for the dependent electrical mines, a sum of £1,500,000 would allow of a submarine defense of each of those 280 vulnerable inlets on our coasts, consisting of one-half of the whole material considered necessary for the defense of the close harbor. Now this quantity may I think be taken as affording an adequate mean submarine defense for those 280 inlets.

In the method I have adopted of only employing small buoyant fixed mines in a system of submarine defense, I do not see any necessity for complicating such a

system by the addition of special fixed mines, or other means for the prevention of interference with the real defense by the enemy's boats; for if, whilst attempting to damage the defensive fixed mines, one of them be struck and short circuited, I should most decidedly not hesitate to fire that particular one, with the probable effect of destroying the boats carrying out this work of destruction, or at any rate deterring a repetition of similar work. Of course by so doing it may be said that a mine is wasted, and a gap caused in the line of defense; but by the employment of the single main system and small buoyant mines I consider it quite feasible and practicable to reinforce the submarine defense at any time, even in the presence of an enemy; provided that everything requisite for the accomplishment of such has been carefully and thoroughly prepared beforehand, and the submarine defense corps have been practically trained for this special service. This brings me to the question of the organization of a submarine defense corps. With us the work is undertaken by the Royal Engineer Corps, but all the principal Continental Powers intrust the carrying out of this work to the naval Service.

Now the whole defense of any harbor must be a homogeneous work, if it be ever expected to successfully stand the crucial test of actual war, and therefore the old saying, "that those who plan the forts should also plan the torpedo defenses," must be considered as only partially correct, for the resultant plan of defense of any port should be the outcome of a joint committee of naval, artillery, and engineer officers; and the actual execution of the submarine portion of the defense should be placed entirely in the hands of the naval department; and this, I venture to say, must appear self-evident, when it is duly considered what the details of such work consists of; and how infinitely more adapted for lighter, boat, and submarine work those are who, as it may be said, are born to it, than men of the shore, as to all intents and purposes military men are. I trust it may not be conceived that I undertake the value and efficiency of the Royal Engineers, than which a finer or more important corps does not exist; but I do think that the work of the sea should be performed by seamen.

Then coming to the subject of the coast defense of the British Empire—a subject of vital import, involving as it does our immunity from invasion, the power of upholding our foreign prestige, and thus the preservation of peace to the Empire now and always,—submarine defense, if carried out in a thoroughly practical and real manner, and suiting the different means adopted to the peculiar exigencies of each particular place, will assuredly prove of immense benefit by enabling us to utilize to the full the power of our Navy. Of course, the principal naval ports, such as Portsmouth, Plymouth, &c., and strategic points such as Gibraltar, Malta, Hong Kong, and others, are, or will soon be, amply provided with a means of submarine defense; but it is to the innumerable commercial ports, harbors of refuge, coaling ports, inlets, and open beaches which are to be found around our home and colonial coasts, many of which it might be absolutely requisite to securely protect, that I more particularly refer here, and in the safeguard of which submarine defense would prove of paramount importance. Captain Colomb in his Prize Essay of 1878 says—

"If the enemy is to be kept at bay by a home defense of any kind, I should think that a cordon of coast torpedoes, fixed and locomotive, in the hands of a British volunteer force will do it," in which I most cordially agree with him.

A volunteer torpedo defense corps should consist principally of the seafaring population of the different ports—men thoroughly accustomed to boat work, and possessing an accurate knowledge of the characteristics of the particular place to which they belong—and thus essentially adapted to the performance of the work of submarine defense. Little or no training would be needed for the greater portion of the force, as these men would have only the comparatively simple work of laying out the main and branch cables and planting the dependent electrical and self-acting mechanical mines. Then, having ascertained the number of men at each port it is determined to defend that would be capable and available for such service, a muster of them from time

to time would suffice to secure their attendance when called on. The number, condition, and power of the steam tugs, launches, and lighters available at the different ports for the work of laying down the systems of submarine defense and guarding the same would, of course, have also to be ascertained and considered. At each port a few specially instructed members of the force would be needed for the work of manipulating and fitting up the system; no highly scientific training would be needed, but actual practical knowledge of the mode of working the instruments and batteries of the particular system that it is decided to adopt would have to be thoroughly taught. The plan and mode of defense should be determined on beforehand, and all the material prepared in readiness for carrying out the same. The foregoing no doubt seems a very offhand and rough scheme of organization of a volunteer torpedo corps, but with the experience I have gained from carrying out similar work with Turkish and Chinese sailors who had had no previous training whatever, and not one of whom had ever heard of, much less seen, a torpedo, and whose language I was ignorant of, I venture to say that a scheme based on those lines would prove a practical and efficient one.

The submarine defense I would propose to adopt with such a scheme would be the simple buoyant dependent electrical fixed mine, in connection with a simple method of single main cable or rheotome system, and the McEvoy improved self-acting mechanical fixed mines. Locomotive submarine torpedo-boats, if used, should be entrusted to the regular force, and I believe a naval volunteer torpedo defense corps, carefully, and above all practically, matured, would—as an auxiliary—be to the Navy what the Volunteers are to the Army—than which no higher praise could be accorded it.

This concludes my paper, which, though it be terribly incomplete and far too concise, yet may, I hope, prove of some value in raising a discussion on the many points I have been forced to leave untouched, or only cursorily glanced at, in which, I hope, those gentlemen far more able and capable of dealing with them may join and give us the benefit of their vast knowledge and experience. I have only to beg to offer you, Admiral Horton, my most grateful thanks for your kindness in presiding, and to express the deep obligation I feel I owe to my audience for the patient endurance displayed in listening to what has unavoidably been an incomplete and dry paper, and one full of dogmatic opinions. As a result I can only hope that some of you may become imbued with the same strong opinion as myself as to the essential value and power of submarine defense.

I now proceed to describe Captain McEvoy's inventions.

I will first explain the mode of working the invention known as "The McEvoy Single Main System."

The title is intended to convey a system of submarine defense by which a number of mines are controlled and fired through a main cable of any length, but containing only one core or path for the electric current to traverse, which current enables all the various modes of firing and tests connected with any system of submarine mines to be accomplished. Hitherto, for this work, it has been necessary to use a separate core or path for each mine.

The principal object of this invention is the combination of simplicity of manipulation with great economy.

The single main and multiple main systems are shown and compared where Fig. 7 represents the former, A being the shore instrument and J the junction box, inside of which is placed the sea or rheotome instrument; and Fig. 8 represents the latter, T being the test-table, S the shutter arrangement, and J′ the junction box.

The advantage of the former method over the latter in point of simplicity and paucity of connections is obvious from the plate, being as 1 to 2; and this advantage is still more patent when we take the case of the connections in a torpedo-room from which a number of mines —say fifty—are controlled. In this instance, using the McEvoy system, there would be only 5 main cable and 35 other connections, giving a total of 40. While using the multiple cable system there would be 7 main cables, necessitating 49 connections, which, with the 63 other wires, makes a total of 112, or as 3 to 1 in favor of the McEvoy system.

Then another advantageous feature of this method is that due to the lightness per mile of its main cable, weighing as it does, one-third less than the multiple main cable per mile, thus making the laying out of such a work far more handy, requiring less time, and less expense; further, the gain in economy by the use of the McEvoy system owing to the extreme comparative cheapness, namely, as as 1 to 4, of its main cable, which constitutes the chief item of expense in sub-

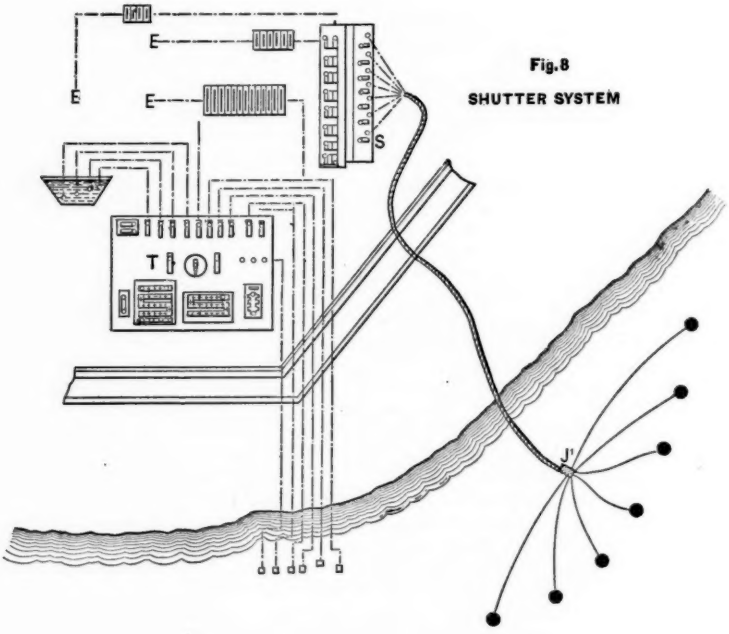


Fig.8

SHUTTER SYSTEM

marine defense, is yet another very important feature to be considered; and in the matter of the foregoing points of vantage on the side of the McEvoy invention, no one, however biased or prejudiced, can take exception thereto.

Before explaining the mode of manipulating this invention, it will be necessary to state, in general terms, the requirements of a perfect single main cable system:

1st. Its manipulation must be simple and practical, and not requiring the services of a skilled electrician.

2d. It must be certain in all its actions.

3d. It must be capable of firing either at will or by contact.

4th. It must be able to denote the electrical state of each mine by comprehensible and easy tests at any time.

5th. It must afford certain indications of any severing or damage of either main or branch cables.

6th. It must denote the number of any mine exploded or struck.

7th. It must afford indication of the sinking of any mine.

8th. There must be no possibility of a switch or key being left in its wrong position.

[*Note.*—Then followed a general explanation of the system.]

Having thus shown you the capabilities of this invention, I will mention, and I hope overrule, the few objections that might be preferred against it. The sea instrument is of course the main objective point:

1st. It may be thought to be too deli-

cate an instrument to be placed under water, and in a position difficult of access, and on which the working of ten submarine mines depends.

Twenty or even ten years ago, these objections might have been made with some show of reason; but nowadays, with the practical knowledge that we have of the satisfactory working of intricate pieces of mechanism under an excessive strain—such as telegraph and other instruments—no one would think of entertaining any objection to the adoption of an electrical instrument solely on account of its apparent delicacy of construction. I say apparent, for it can be only so to those who are unaccustomed to manipulate such instruments. Now, this sea or rheotome instrument of Captain McEvoy's, which is a very much simplified adaptation of the Wheatstone A B C telegraph instrument, would, on actual service, have to stand comparatively little work—probably not more than four series of tests each day. This instrument, and a similar one I had with me in China, have been often subjected in one day to far more work than would be the case with one of them on actual service in the course of a month's ordinary work; and yet we have never had occasion to remove the lid of the instrument case, for repairs or other matters, though this and the one used in China have been hard at work for many months.

Next, as to its being placed under water. This is, I venture to say, a very simple matter, involving merely the construction of two separate brass boxes, or more if it be considered necessary, one inside the other, both watertight, and capable of resisting a pressure of water, varying according to the depth at which it would be placed, a work, with the present perfection of all mechanical details, easily and practically attainable.

2d. It might be thought that owing to electrical leakage the balance may not work satisfactorily, and therefore uncertain tests afforded, after a group of submarine mines has been planted for any considerable length of time. Now, this fault caused by leakage, which I have greatly exaggerated, would be easily remedied by merely increasing the power of the signal battery, by the addition of a cell or two: for the failure of the signal current, which is supposed to be kept at a normal strength, to correctly swing the test needle, is due to its current, or a portion of it short circuiting through the points of leakage.

This completes the explanatian of this clever invention, which has been adopted by several foreign governments, and I trust I have most favorably impressed you with its power and practical usefulness for submarine defense; any way, I believe you will concur with me in declaring that it deserves a fair and honest trial.

Captain McEvoy supplied one of his original sets of these instruments to the Chatham torpedo authorities in 1879, but so far, he has not had the satisfaction of receiving an expression of opinion as to the merits or demerits of his invention; the Chatham set does not embrace all the late improvements.

This particular set of Captain McEvoy's system is adapted for a group of 10 fixed mines. Now, it has been often urged that this is too great a number of mines to be manipulated by one set of instruments and dependent on one main cable, and that also a far too large gap would be formed by the loss of one such group through the discovery of its main cable by the enemy.

Take the case of the close harbor in Fig. 4—here 100 dependent fixed mines are estimated for its defense, necessitating 10 sets of instruments, and 10 main cables. If only 7 mines compose each group, then to obtain a similar defense there would be required 14 sets of instruments and 14 main cables; and in the case of 5 mine groups, 20 sets of instruments and 20 main cables would have to be employed, and I do not think the exponents of the reduced group system would consider the advantages claimed for it to be attained by the use of a greater number than 5 mines for each group: then by substituting the reduced or 5 mine group system for the 10 mine system, it is evident that far greater time is required for the work of laying out the defense, the cost is nearly double, and the simplicity of the work much impaired by the increased number of main cables and instruments; also the chances in favor of a main cable being discovered by the enemy are exactly doubled, therefore, weighing carefully the advantages and disadvantages of the two systems, I

think it will be generally agreed that the 10 mine group system is by far the preferable one

In conclusion, I will proceed to explain the very latest of Captain McEvoy's inventions. It is termed a "submarine detector," Fig. 9. It is constructed on

MC EVOY'S SUBMARINE DETECTOR.

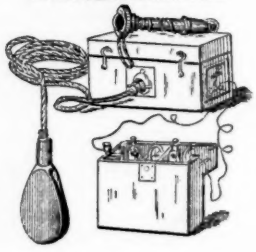


Fig. 9.

the principle of the induction balance, and consists of an instrument box, small battery (which may be either a magneto or ordinary chemical battery), and the detector with its cable and box; this detector cable is composed of four insulated cores, and by an ingenious contrivance, the connection of these four cores can be made or broken by one movement. Within the instrument box is placed a set of induction coils, and a vibratory magneto-electric apparatus, the telephone in connection with which can also be laid in the box; the battery poles are always connected up, but the circuit can be broken or closed at will, by means of a small key; within the detector itself is placed a set of induction coils. The action of this invention is as follows: the circuit being closed, and the telephone placed to the ear, a very distinct and regular increase of a humming sound will be heard on the near aproach of the detector to any piece of metal however small, culminating on actual contact therewith. This invention, as may be easily understood, will prove of great value in an infinite variety of ways; as specially connected with submarine defense, it will be found of great use in discovering the position of submarine fixed mines—both dependent electrical and self-acting—also junction boxes, cables, etc., when it is required to cover the same.

THE DEVELOPMENT OF ELECTRIC LIGHTING.

By J. E. H. GORDON, B. A.

From the "Journal of the Society of Arts."

Among all the great industries which in this wonderful last fifty years have been developed, there is none, perhaps, that has had so stormy a birth as the industry which we have met to speak of to-night, namely, that of electric lighting. We must remember that the public know very little indeed about electricity, in fact, nothing. Even in the early days of railways, although there was much ignorance about steam, still everybody had seen a kettle boiling, and had some vague idea of what steam might be, even if he did not know what it could do. But the public do not know what electricity is, nor have they any knowledge of its laws; therefore, at one time, they were ready to believe any statements made to them about electricity. Nothing was too extravagant, too startling, or too ridiculous for the public to believe in the early days of electrical enterprise. We all remember that panic in gas shares, which occurred about three years ago, when numbers of the public rushed to their brokers, and directed them to sell their gas shares at any sacrifice, to throw them away if there was any liability on them even, but to get rid of them. Why? Because a telegram had come across the Atlantic that Mr. Edison said he had made a discovery which would supersede gas. Few remember that, even with the most perfect discovery, it would at least take a little time to provide for an industry involving a re-investment of capital in England alone of about £100,000,000 sterling, for that is about the amount invested in gas. It was imagined that this great change was coming instantly. How-

ever, this change did not come instantly. Then they said Mr. Edison was an impostor, and that the electric light was a failure, because it was found that we could not undertake to supply one hundred lights, when the whole plant was made for the supply of one hundred lights only, at the same rate as one hundred gas lights, when they form part of a system supplying, perhaps, one million.

You must not for a moment think that Mr. Edison was to blame for this. Mr. Edison is a genius, and one of the greatest inventors of the age, and he has, in a very high degree, that poetic and prophetic insight which is able to see beyond the trammels of difficulty, and to know in his own mind, for certain, what will come in the future. He saw that the thing could be done, and said so. And, further—it is, perhaps, a failing of inventors, and being an inventor myself I may say it—Mr. Edison, like all inventors, has that enthusiastic imaginative temperament which is necessary for the development of inventive skill, and possibly he may sometimes have slightly confused what he was certain shortly would be done with what had already been done.

Now, this development of electric lighting has suffered to some extent from its enemies, but of course it is understood that gas shareholders are its natural enemies, and will do all they can to retard it; it is perfectly fair and right they should do so. We regard them as fair and open enemies; we are quite willing to fight them on their own ground, and hope the best man will win. But they have not done us much harm—in fact they have done us good. If there had been no other light to fight against, electric lighting would not have developed as fast as it has done. But electric lighting has suffered terribly, not so much from its enemies as from pretended friends. It has suffered much from the operations of persons who, while professing to be interested in electric lighting, and to desire to hasten its adoption, have only been interested in the progress of Stock Exchange operations, and the formation of bubble companies.

Whenever any industry is started which is at all new, this will always occur, and the extent to which it occurs is measured to a certain degree by the credulity, and more by the ignorance, of the public. If companies are brought out in connection with a subject the public know all about, there is not much chance for the public to be deceived; but if it is a subject they know little about, they are easily deceived; and when you come to a subject like electricity, about which the public know nothing, there are special opportunities for the speculator. I hope the ground is now cleared, and that these bubble companies, having satisfied their promoters, are disappearing, and making way for honest, legitimate enterprise to go on.

Now to turn to the more practical and the more important part of our subject, we have to think what is the problem which has to be solved in the establishment of electric lighting; it is, first, to provide a perfectly steady, perfectly safe and reliable light; and what is very important still, but which is second, to provide that light cheaply. It is no use getting a light a little cheaper than another, if it is to go out or to blink. Our first consideration must be to make the light perfect; the second, following closely, but still second, must be to make it cheap. This problem must be regarded as a whole, I mean the problem of making it perfect. It has been attacked too much in detail, and the reason of that is that, for success in electric lighting, the knowledge of several branches of science is required, which are not often united in the same person; an electrician, for instance, is very often not a first-class engineer. It is no use getting a little more out of your dynamo if that dynamo will not fit the engine; if you have a certain dynamo that works conveniently with your engine, it is no use making the dynamo one or two per cent. better, if the alteration causes you to lose ten per cent. more in transmitting power to it. You must regard the engines, dynamos, mains, &c., all as one complete system, and you must remember that if anything goes wrong, the public will not make excuses for the lamps like we may make in the laboratory. They will not say it was not the dynamo's fault, but it was the engine's fault, or the boiler's fault. All that the public would be concerned with was that on this or that occasion the light went out. Therefore we must not despise anything, however foreign it seems to our subject, if it

will help to make the system, regarded as a whole, perfect. The electrician knows very well that the principle of a dynamo is to move a coil of wire through a magnetic field, and he is very apt, when he is a pure electrician, to think that he has invented a wonderful dynamo if he gets a coil of wire that will go through a magnetic field; he says here is a magnet, and here is a coil of wire, the coil is to be thin and the magnet strong, and the coil is to be moved fast through that field. Then some outsider says. "How are you going to secure it, and attach it, and support it?" "Oh," he says, "any practical man can tell you that;" but I am afraid that when "any practical man" has found out that, he is apt to patent it and keep it to himself, and sometimes he says that what the electrician has given him is the very smallest part of the invention. Perfecting dynamos is an engineering problem, quite as much or more than an electrical problem.

We must not spend time in going into the details of electric machines, but there are one or two points I may be pardoned for alluding to. It is bad policy to cheapen your system by endeavoring to greatly cheapen the dynamo. The contract price to be paid by a company for electric lighting plant will be one sum for engines, boilers, dynamos, mains, buildings, &c., and it does not matter if the dynamos are a little cheaper, and the engines dearer, so long as the total sum remains the same. But whatever else we economize in, we must not economize in the dynamo, for this reason that the cost of the dynamo is comparatively a small fraction of the cost of the plant, but the dynamo is the very vital heart and lungs of the whole affair. If anything is wrong with the dynamo, it is no use having the most perfect engines and the most perfect lamps, the lights will go out. Therefore, the dynamos must be perfect, and any economy, any extreme cheapness that is required, must be achieved in some other part of the plant.

Now, this question brings us to a controversy which has been going on, and has been universally discussed ever since electric lighting was first heard of, and which I think will continue to go on for some time, that is, the controversy between the relative merits of high-speed and low-speed dynamos. It is necessary in a dynamo that the coil of armature wire should pass at a certain speed through the magnetic field, and that speed can be obtained in two ways; the wire is wound upon a wheel, and you can either have a small wheel which revolves many times a minute, ar a big wheel revolving few times a minute, and you get the same speed of the rim in each case. The controversy between high and low-speed dynamos means this: will you have a small wheel revolving very fast, or a big wheel revolving very slowly. The first and natural opinion is have a small wheel revolving fast, for you can make the dynamo a good deal cheaper that way; it takes up less space, and altogether seems more convenient. I think everyone, when he begins electric lighting work, approves of high-speed machines. I did, myself. at one time, very strongly; in fact, less than two years ago, I wrote an article in the *Quarterly Review*, in which, if I recollect rightly, I said the dynamos of the future "will, we believe, revolve much more rapidly than at present; their speed will only be limited by their tendency to fly to pieces." Then my friends and I set to work to build a dynamo on the principle I had laid down in the *Quarterly Review* article. We soon found that in a large high-speed machine there was a great deal of difficulty in getting the power into it at all. You had to put belts to it, in fact a number of belts and counter-shafts, and there was always a good deal of slipping. Then the belts going at high speed used to make a most terrible noise; there was a deafening roar in the dynamo-room, and the whole building used to shake. All these things were bad in themselves, but they were worse in this respect, that all these vibrations, whether of air forming sound, or of the building itself, required mechanical force to produce them. and every bit of that force was stolen from the steam-engine, and taken away from the force that ought to be used in producing light. I suppose this ought to have convinced me that high-speed machines were wrong, but it did not. We went on, we tried a machine, it worked very nicely, indeed, for an hour, and we got excellent electric results, and were very well pleased. Then certain vibrations began to get worse, and I thought it advisable to send the workmen

away. There was one safe spot where the person attending the machine could stand, from which I was able to watch what happened. The experiment was conducted in a cellar at Wharf-road, all vaulted with brickwork backed by the earth of the street, and it was so hard that when, on some occasion, we wanted to put a spike into it, we were unable to penetrate it at all. After a few hours' work the dynamo flew to pieces with a loud explosion, and I have here some of the few fragments that were left of it. Here you can see the fracture of a massive piece of iron that was caught by it; here are portions of the holders of the revolving magnets. I have not much of it here, the rest of it was picked up in a shovel. The only large piece which was found was a piece which weighed 1½ cwt., which struck the hard wall of the cellar (the distance from the dynamo being about tweuty-five feet), and cut a hole two feet in diameter and two feet deep. Another piece skimmed along the vaulted roof, and made a series of grooves in which you could put your two fists. After that experiment we thought we had had nearly enough of high-speed dynamos —in fact, we thought we had nearly enough of dynamos altogether. Here, perhaps, although it hardly belongs properly to the subject of the paper, I must ask your indulgence if I turn aside for a moment, to say a few words of tribute to those friends who, both by their moral and material support, helped me through that very difficult time. After this explosion, when it might have been fairly thought the whole attempt was at an end, my friends met, almost among the ruins of the dynamo, and in a few days they subscribed a large sum of money, and said to me, "Go on; build us another dynamo ten times as large as the first, only," they said, "make it strong enough this time." We set to work and built a second machine, and this time we went on very different lines. We made the wheel enormous, and made it run very slowly, taking good care that the whole thing was strong enough. The first machines had taken two to two and a-half years to make, the second machine took about eight months, and this was last year, and the experiments cost a great deal of money; one thousand pounds went after another, and still there was no result. Things seemed far from completion, and the money which had been handed to me to build the machine was spent three times over before the machine was finished; still my friends said, "go on, if it costs three times as much as you expected, you must make it do three times as much work." At last we were all ready to try the experiment, and for the last week or ten days I may say we had given up going to bed; it was of no use, for we could not sleep, we used to go to bed for two or three hours, but we spent nearly all night in the factory. At last my friend, Mr. Clifford, the Telegraph Construction Company's chief engineer, and myself, began the final trial; we began on a Saturday morning, and thought we should be ready to start the engines on Saturday night, we got the steam up, but first one hitch occurred, and then another, before we could start, and at last it was three o'clock on Sunday morning before we made our first trial. That failed completely, the machine did nothing; we looked over it, and saw what was possibly the cause of error, and set to work to change the connections. Now, if you are changing connections in little dynamos, it is simply a matter of unscrewing two or three screws, and changing the wires, but with this large machine, it was not so simple; it took as many men as could cluster over it until six o'clock in the morning; then we got a little better result, and went home for a few hours' sleep. We started again early on Monday morning, and at nine o'clock on the Monday evening we were ready for the trial. The experiments were made at the Telegraph Construction Company's Works, at Greenwich, works which are about a third of a mile long, and cover fourteen acres; there are 1,200 or 1,400 lights all over the works; and as the cable department was then busy, there were about 1,000 men at work, and a little glimmering gaslight over each lathe. When I turned the valve, the whole place burst into a blaze of daylight at once, and we felt at last rewarded for that three years of anxiety we had had before.

Now, what are the chief advantages of a big machine as compared with a small one? I think the chief advantage of all is that we can dispense with belts. With a big machine we get the necessary veloc-

ity by the largeness of the wheel, and therefore, can cause it to revolve only the number of times in a minute which is not too great for the steam-engine to revolve, and can connect direct to the steam-engine. Mr Edison was the first to point out the importance of this, and his was the first very large machine which was made. He has constructed a very large dynamo, which works 1,300 of his lamps, equal to about 1,000 20-candle lamps, his being 16-candle. It has been worked extremely successfully in New York, and also in Holborn; and I will now throw on the screen a picture of it, then I will show you some of the important points, not of dynamos generally, but of a large machine as compared to a small one. You know that a dynamo machine consists of some apparatus for causing a coil of wire to revolve opposite a magnetic pole, or else magnetic poles to revolve past a coil of wire; in the one you see before you, the shaft is geared direct to the steam-engine, no belting at all being required; it is driven at the speed of 350 revolutions a minute.

I now come to a very important point, which is where the current is taken off. Of course, if a current has to be taken from a moving coil to fixed wires such as the conductors that go to the streets, there must be sliding or rubbing contact of some sort, and you have all seen in ordinary dynamos the contact brush or commutator, and there is always a little sparking. As the current gets greater, that sparking gets greater, not proportionately, but still it is greater when you get a large machine. I must say myself I think the current for 1,000 or 2,000 lights is about the biggest that can be taken off by rubbing contact, but I never heard that with this 1,300-light machine there has been any difficulty with this. Still, as a matter of prudence, I should not consider it advisable to take enormous currents through rubbing contacts. I am speaking of currents which will supply as many lamps as come from our big gas works. Therefore when we designed this machine I have been speaking of, we arranged it somewhat differently. We used an arrangement which is not new, but was never applied on a large scale before, namely, causing the magnets to revolve, and the coils to be fixed. That enables the current, however great, to be taken off without sparking at all, there being a metallic connection the whole way from the fixed coils to the mains.

Our machine has been worked up to nearly 2,000 lights, and we were able to get this off a fraction of the coils, and we have no doubt, it will give about 5,000 lights with adequate engine power. We call these 5,000 lights the baby ones; there will be much bigger ones made some day, we hope. There are 32 magnets, which revolve between fixed coils whence the current is taken off. I must be pardoned in my illustration of big machines for going so much into the details of my own, and so little into the details of the excellent machines of Mr. Edison. My excuse must be, first of all, I am not so well acquainted with the details of Mr. Edison's as with my own; and, secondly, from the natural feeling a parent has for his own child, for he always believes it to be the finest child in the world.

We now come to a requirement which is common to all large machines, namely, a method of adjusting and regulating them while they are going. You see we have to keep the pressure constant, and we have a varying demand. We put on a number of lights when we start, and then somebody turns out a number of lights; later on, somebody else turns a number on, and we have to keep the pressure absolutely constant. Now, with any machine, such as this, if a thousand lights, say, are on, and another 500 are put on, the pressure will drop, and the 1,500 lights would not be in proportion so bright as the former 1,000. Similarly, if 500 are taken off, the remaining ones would get brighter, and break the lamps; and, therefore, means for compensating for these changes have to be provided. The way in which the regulation is done is by varying the strength of the field magnets. These magnets which are fixed on the big revolving wheel, are not permanent magnets, but are magnetized by the current of a small direct current machine. At present we use a very good little machine made by Mr. Crompton. This small direct current machine is driven by a small separate steam-engine, and by varying the speed of this small steam-engine, we can vary the strength of the current in the magnets, and so we can alter the pressure just as we want it. Of

course we have to alter the pressure according to the requirements of the district, and this is the way the regulation is at present done. The picture on the screen represents the regulating room of our works at Greenwich. First of all, we have to see what pressure is right, and for that purpose we employ a photometer, an iron rod which casts two shadows on a screen, one the shadow from a candle and the other the shadow from an electric light further back, the relative distances being so adjusted that the candle power of the lamp is correct at the moment that the two shadows are equal. By shifting the position of the candle we can work to any candle power we prefer. The lamp employed being a fair sample lamp, we know that if that lamp is right all the others are right, but we have one or two connected from different parts of the factory, which can be turned on by means of switches. Now, suppose some one at the other end of the factory turns of 100 lights, when there are a large number on, that would not be perceptible in the factory; but the man here can see the change of brightness much more readily than anyone can in the open room or yard, and he at once sees that the pressure has run up a little bit. He then turns this valve a little, which partly shuts the tap, and diminishes the supply of steam to the small engine, that diminishes the speed and the strength of the magnets, and so takes the pressure down as required. Similarly, if 100 lamps are put on, he finds the brightness drops, and he has to open the valve, and make his small engine run faster. There is one very important feature which it has been necessary to put into this regulating apparatus, and that is due to the property of the human eye to accommodate itself gradually to changes of light. The pupil of the eye expands and contracts, and takes in pretty nearly the same quantity of light, if the illumination is within certain limits. Although the eye is very sensitive to sudden changes of light, yet if you make the change sufficiently slowly, you allow the pupil time to expand or contract, and the change is not noticed very well. Therefore, instead of turning this valve rapidly, it is turned by a slow screw, so that it takes at least a minute to make a change of light equal to one-candle power. The result is that, even if a considerable change has to be made, such a change is never noticed at all. At the back of the room there is a steam-pressure gauge, showing the pressure on the boiler, and an indicator showing the speed of the large engine, and two men stand here on duty, in turns, all night, to work the valve.

You may say that this is an expensive way of regulation, on account of the cost of men's wages; but what we have to consider in the commercial aspect of electric lighting is not the price of working each machine; but the price of working each lamp. It would have been ruinously expensive to have one or two men to attend to a small machine, but when their wages are distributed between 5,000 or 15,000 lamps, it becomes a very small item of expense indeed, although those same wages distributed between 500 or 1,000 would be very extravagent.

There is one small point about this machine, before we leave the technical part of the subject, which I may be pardoned for mentioning; although it is a purely scientific point, I think it is of some general interest, as showing the kind of difficulties which the designer of any new engineering work has to encounter. In our first model machine we made the same number of coils as there were magnets; that is to say, there were a series of round bobbins in that disc of the machine, and a similar number on the revolving wheel, and currents were induced in the way usual in that clsss of machine. On the first experiment we put one coil on the small experimental machine, and got a good result, but when we put on the next coil alongside, we found the mutual action of the two coils pulled down the amount of light produced nearly 50 per cent., in fact diminished the power of the machine nearly one-half. A little study of the laws of induction will show you how that occurred. It is a well-known law that a varying current, under certain circumstances, will induce a current in an opposite direction to itself. Here was a current traveling in one direction, which induced a current in the opposite direction in a neighboring coil, so that we got two opposite currents, and we only got the difference between the actual current induced by the magnet, and the back current induced by the next coil. The

practical result was, that the efficient lighting we got out of the machines was reduced to about one-half. To get over the difficulty we made a number of fixed coils, twice the number of the magnetic poles, flattened them, and squeezed them together, so that each pair of coils was acted on alternately, and between each there was a coil which was not in use at the moment; therefore, although there was a tendency to induce back currents, yet each pair of active coils being separated by an intervening coil, the action was so small as not to be perceptible, and thus the quantity of electricity we could get out of the machines was nearly doubled. We hoped we had now got the dynamo perfect, and that we had solved the problem and got to the end of our troubles. We had got the dynamo as perfect as we knew how, but we found our troubles only beginning. It is a small portion of the problem of electric lighting to get the dynamo perfect, because there are so many details to be attended to. In putting up a plant for 10,000 lights in the middle of a populous town—a town of wealthy houses, where the inhabitants do not at all like smoke and waste steam — there are a great many matters to be attended to. There is the dynamo house with three dynamos, each working five thousand lights, two to be always at work and and one in reserve, the whole plant being designed for 10,000. Then we have an arrangement so that the mains are laid double. That is to say, each house has half its lights from one dynamo, and half from another, so that, supposing an earthquake upset one of the dynamos and put it wrong, then only half the lights would go out; the town would not be put in darkness. There is one class of accident which may occur to any machine, and it is, I think, about the only difficulty which large dynamos are liable to, that is, getting a hot bearing. But an engine driver is not worth his wages if he cannot keep an engine with a hot bearing going for a quarter of an hour, and supposing he finds he has a hot bearing, all he has to do is to start the spare dynamo, get the speed of that the same as the speed on the other, start the exciting engines, get the pressures constant. then pull over the switch, and all that will happen will be a slight jump in the light, and then the engineer may instantly stop the heated dynamo and attend to the bearing. The engines are condensing engines, each dynamo to have two, and they will require about 510 indicated horse-power when at full work. Each engine is calculated to have a power of 275 indicated horse-power, so as to give about 550 horse-power available, which is sufficient reserve. Again, there are boilers in reserve; 4½ boilers would give sufficient power, so that there will be always two boilers standing quite idle, which can be cleaned. There is a large crane running along the roof, which we used to put the machinery into its place, and to lift any part of it as may be required for repairs.

I have spoken of condensing-engines, and I think we must have condensing-engines, at least, in all important and wealthy towns. There are certain advantages of economy which are matters quite open to discussion, but I think they are more economical even in London, where water is expensive. We have seen lots of engines for small electric light plants which are not condensing, and they do very well, but they have all been small. If you only want 10 or 20, 50 or even 100 horse-power, you may send the waste steam up the chimney, it disappears in the air, and you hear no more about it; but if you have over 1,000 horse-power, even in this station, which is regarded as a small experimental one, and send the waste steam into the air, two or three unpleasant things will happen. First, you will choke the chimney, because the effect of the steam will be to cake the soot, and so spoil the draught, and some day you would find the furnace would not draw; secondly, that steam would attract all the London blacks, and form a fog to which our present fogs would be as nothing, and that would be a bad introduction of the electric light, one of the great arguments in favor of which has been that it is to keep our houses clean. With a condensing-engine the waste steam is all condensed, and goes away in the form of water. It is a hard saying to say there must be condensing-engines, because condensing-engines very greatly increase the first cost, but in spite of this I say that we must make up our minds that, if we have the electric light at all, we must be pre-

pared to pay for condensing-engines. We must remember, too, that there is a special clause in the Electric Lighting Act, and in the draft provisional orders, pointing out that no Parliamentary powers, conferred on a corporate or other body, are in any way to be regarded as a protection to them againt being indicted for a nuisance if they should cause one. Therefore, we must arrange the plant so as not to cause a nuisance. With electricity there is more loss in transmitting it to a long distance than with gas, so that we cannot place our electric lighting machines at a great distance from the town. About half a mile radius is a convenient distance, and therefore, the stations must be tolerably central.

As to the space required, these engine-houses, for a 10,000 light plant, require 72 feet square; that is to say, two strips 72 feet by 36 feet. If it were more convenient for the site we might set the boiler-house end to end with the engine-house. Then we have to get a supply of coals. We cannot put the coals on with a shovel when working on this scale. We have to think of bringing the coals in through a populous neighborhood, storing them so as not to cause a nuisance, and feeding them so as not to cause smoke, and also so as not to have an enormous staff of firemen, whose wages would run away with our profits. We may assume at once that we must have what are called mechanical stokers to the boilers; that is to say, that each furnace is fed, not by shovelling in coals, but by a little steam apparatus, by which the coal is discharged into a hopper, and slowly screwed into the furnace. That has the advantage that it enables us to burn much cheaper coal than we could otherpise do. We have here a coal store which will hold about three weeks' winter supply, so that we need only coal about once a fortnight, and we can do it at night. The floor of this coal store is higher than the level of the boilers. The coal wagons will stop outside; there is a small crane by which the sacks are all taken up, the coal is emptied into the store until it is full, and that is the only time in which it is lifted. Near the bottom of the coal store there is a trap-door, and the coal comes out, and is run into trucks running on a raised tramway, and is discharged by its own weight into the hoppers of the stokers. There is, again, a second underground tramway for removing the ashes, so that the coal requires no handling at all.

You may say this is all very pretty, it is a very nice dream for the future, but what is it going to cost? People are not going to buy electric light at two or three times the cost of gas. That is a very important question, and he would be a very bold man who would speak too strongly on the subject, but yet I think we may say, not that electric lighting will be dearer than gas, but that it will be almost immediately cheaper. I believe that in the future it will be about two-thirds the price of gas; and I am quite certain that at present it can be supplied in London at the same price as gas, when supplied on a moderately large scale. I have worked some estimates (see next page) of the capital expenditure, and the working cost for an electric lighting plant, and there is not much difficulty in getting out the total expenditure accurately. The doubtful point is what the revenue will be. The estimates show the expenditure of capital and the annual expenses for electric lighting plant of two sizes, one for the supply of electricity to 60,000 lamps of 20 candle-power, and the other to 10,000 lamps. In each case we can always count upon putting up half as many more lamps as we should supply, for never more than two-thirds of the total number would be alight at the same instant. First comes the capital expenditure, viz., the price which would be charged by the manufacturers for the whole plant, that is, for machines, dynamos, mains, chimneys, and, in fact, bringing a pair of poles into every house, and starting the concern. Those are not estimated sums; they are taken from tenders which my company has actually furnished to corporations, so we know that the expenditure would not exceed these prices, because we have actually offered to contract to do it for the terms mentioned. The annual expenditure is another matter. It depends to a great extent on the number of hours per annum the lights are burning. I have spoken here of 2,000 hours, but I find there has been a good deal of misunderstanding about what is meant by that. I do not mean that all the lights will burn for 2,000 hours, but what I

PLANT TO SUPPLY ELECTRICITY SIMULTANEOUSLY TO FEED 60,000 LAMPS OF 20 CANDLE-POWER EACH. EQUAL TO 85,000 OF 14 CANDLES. CAPITAL EXPENDITURE, £220,000.

Annual Expenditure, lamps burning 2,000 hours per annum.	
Depreciation and repairs	£8,000
Slack coal, at 11s.	7,100
Water, at 6d. per 1,000 gallons	7,100
Oil, &c.	850
Wages and superintendence (63 persons)	5,390
Rent, rates, and taxes	1,000
Office expenses	500
Directors' fees	1,000
Renewal of incandescent lamps	12,000
10 per cent. of dividend on capital	22,000
Total required revenue	£64,940

85,000 14-candle gas burners burn, in 2,000 hours, 850,000,000 cubic feet, which would produce £65,000 at 1s. 6½d. per 1,000 cubic feet.

PLANT TO SUPPLY ELECTRICITY SIMULTANEOUSLY TO 10,000 LAMPS OF 20 CANDLE-POWER EACH, EQUAL TO 14,000 OF 14 CANDLES. CAPITAL EXPENDITURE, £50,000.

Annual Expenditure, lamps burning 2,000 hours per annum.	
Depreciation and repairs	£1,500
Slack coal at 11s.	1,230
Water, at 6d. per 1,000 gallons,	1,230
Oil, &c.	150
Wages and superintendence (30 persons)	2,968
Rent, rates, and taxes	250
Office expenses	250
Directors' fees	350
Renewal of incandescent lamps	2,000
10 per cent. dividend on capital	5,000
Total required revenue	£14,928

14,000 14-candle gas burners burn, in 2,000 hours, 140,000,000 cubic feet, which would produce £15,000 at 2s. 1½d. per 1,000 cubic feet.

Gas in London is 3s. 2d. per 1,000 feet.

N.B.—It is not expected that each lamp erected will average 2,000 hours per annum, but that 2,000 hours is the average consumption of the maximum number alight at one time. Thus, if a house has thirty lamps, but not more than eighteen alight at once, the average consumption of that house will be $18 \times 2{,}000 = 36{,}000$ lamp-hours per annum.

mean is, that the average of the maximum number of lights burning at once will be about 2,000 hours. For instance, suppose in any particular house we put up 30 lamps: there are not, as a rule, more than 18 lamps burning at once, and I should not call the expenditure of that house 30 times 2,000 hours, but only 18 times 2,000 hours. We need not provide, in plant, more than sufficient for the total number of lamps likely to be burning at once. I was talking to a gas engineer the other day, of very great experience, and he thought I might count on never having more than half the lamps alight at once, but, to be on the safe side I have taken it at two-thirds. The number of hours lamps burn depends where they are. Street lamps burn nearly 4,000 hours; then come clubs, which burn over 2,000, but in private houses they would burn less. I think, with that reservation, that when we are speaking of the maximum number alight at once, and not of the maximum number put up, we may say that 2,000 hours is not very far wrong. Here is the way the expenditure is calculated. Every year put aside something for depreciation. Of course, the first year there would be nothing spent, and perhaps not for a few years, but some day new boilers will be required, and for that we should go on the reserve fund; therefore each year a certain sum must be put aside for repairs. I have taken that at about £1,500—a certain percentage on one part of the plant, and a different percentage on another. It is a large percentage on the boilers, a smaller percentage on the dynamos, a smaller still on the mains, and a smaller still on the buildings. When the dynamos are run at a small speed, you can diminish the depreciation on dynamos and buildings; high-speed dynamos shake buildings to pieces before very long. Then comes slack coal at 11s. The cousumption of coal has not been guessed at, but is taken by me from figures furnished by Mr. Hill, chief engineer at the Royal Mint. They have lately had a pair of engines put up by Messrs. Maudsley & Field, of 500 horse-power, about the type of engine we think of using. They are not put up for electric lighting purposes, but for driving the machinery of the Mint; they have been working seven or eight months, and the figures for the consumption of coal are from the actual bills. By using mechanical stokers we can use slack coal at 11s., instead of steam coal at 18s. Mechanical stockers do not give us quite an advantage in the ratio of 11 to 18, because 1 lb. of slack coal does not produce so much steam as 1 lb. of good coal, but still there is a very great saving in using slack—about 13 to 18. The actual con-

sumption at the Mint has been 2¼ lbs. of slack coal per indicated horse-power per hour. From that 11s. that item is taken of £1,230. Then there is the water for condensing purposes. Where we get waterside premises, that will cost nothing; but in central stations we must reckon 6d. per 1,000 gallons, and a rough and ready rule is, that the water costs about the same as the coal when you have to pay for it, and, therefore, I have put it at the same price. Then oil is a small item; wages and superintendence includes the chief electrician, chief engineer, and various workmen required for small repairs. It does not include any large repairs, which are included in the first item. To be in the dark room, and attend to each engine and dynamo, requires three men always in attendance, *i. e.*, one engine-driver, one laborer, and one man in the dark room; each of those work eight hours, so that you require three shifts of men. That makes a man's work 56 hours a week, 54 being the ordinary workman's time. They work, of course, seven days a week. Then there is rent and taxes, interest, directors' fees, and renewal of lamps. These must be renewed free of expense, that is, the expense of renewing them must be included in the charge for electricity, whatever it is. I do not mean that if the glass of the lamp is broken it is to be renewed; but when a lamp has been destroyed by the current, it is to be renewed. When the lamp is broken by the current, the carbon alone breaks, not the glass, and the rule will be when the lamp has broken down, but the glass is intact, it can be exchanged without charge for a new one; but if the glass is broken, it follows it is broken by violence, and must be paid for. The total required revenue, including 10 per cent. dividend, you see, is £14,828.

The light obtained from 10,000 20-candle lamps is the same as obtained from 14,000 14-candle lamps burning 5ft. of gas an hour, and they, burning for 2,000 hours, burn 140 million cubic feet of gas, which produces £15,000, which is the required revenue, if gas is charged at 2s. 1½d., the price in London being 3s. 2d. On the larger scale the economy is great. The larger scale we work on the cheaper per lamp will the light be. The light, of course, will have to be supplied by meter, but about that I must postpone speaking to another time.

The introduction of electric lighting has, of course, been attended with many difficulties, but I do not think it has been attended with much more difficulty than must necessarily attend the introduction of any new industry requiring a great re-investment of capital. People who have capital invested in something paying well are shy of taking it out and putting it into something new. If you go to a corporation and say, "If you will spend £100,000 in electric lighting plant you will make a good profit," they will naturally say, "That is all very well, but here is the money we are making from gas, and we prefer that;" and then they say, "Why do you not go in yourselves for this? If it is a good investment, invest your own capital in it, and show us practically it is so." I will not say that is not somewhat hard upon us, but, on the whole, it is a fair enough challenge, and we have made up our minds to accept it. I am not at liberty to say what arrangements are being made, but I hope I shall shortly be able to commence putting up in the West-end of London such a plant as we have already erected; and we made an offer to a vestry, in a district in which we propose to put up the lighting, that we will guarantee that the maximum charge for a quantity of electricity equal to 1,000 feet of gas shall never exceed 3s., and shall be reduced if we can do it. I will not enlarge any more on this, as it would savor much of a very vague scheme, for you to listen to-day to what we propose to do, and it would savor somewhat of boasting for me to say it; but if this Society would do me the honor, in about a year's time, to ask me to read a paper before them again, then, if our work turns out as I hope and expect, I may be able to tell them not what we hope to do, but what we have actually accomplished.

Shipbuilding trade on the Clyde is on the increase, and the returns show a great extension. The output from the stocks in one month was 33,202 tons, against 30,304 tons in the previous year, 21,754 tons in 1881, and 15,874 tons in 1880.

SOURCES OF ERROR IN SPIRIT LEVELING.

By J. B. JOHNSON, Member of the Engineers' Club of St. Louis.

From the "Journal of the Association of Engineering Societies."

I. General Remarks.

It is proposed in this paper to call attention to the ordinary sources of error in spirit leveling, with some effort to arrive at the relative magnitude and probability of such errors and to consider the best means of avoiding or eliminating them. It is only in the last ten or fifteen years that spirit leveling has been brought to such a degree of perfection that it would compare favorably with other geodetic operations. Astronomical determinations, and the measurement of distance on the earth's surface, both directly and by triangulation, have been far in advance of methods for determining the third co-ordinate, viz., elevations above sea level. The latter, however, are essential to a proper reduction of the former, and are becoming more necessary annually in connection with the various problems relating to the weather, the improvement of rivers, the water power of streams, drainage, navigation, railroad economy, and many scientific problems. These interests being so intimately connected with the highest development of a nation, it becomes the duty of the State to make the determination of elevations above the world's common datum plane a vital part of every general scheme of geodetic operations. For so large a country as ours, this involves lines of spirit levels thousands of miles long, and if great accuracy is not attainable, the final errors in the elevations of points in the interior are likely to be material.

Much attention has therefore been given, in the last few years, by various governments in their national surveys to this subject. Switzerland may, perhaps, be said to have taken the lead, but England, France, Germany and America have not been slow to follow her example.

Three departments of our government surveys may be credited with doing what is called precise leveling, viz., The U. S. Lake Survey, recently completed, the Coast and Geodetic Survey, and the Mississippi River Survey under the Commission. The elevation of all the great lakes was obtained with a probable error of less than one foot. The Coast Survey is carrying a line of accurate levels across the continent from Chesapeake Bay to San Francisco, passing through St. Louis. The Mississippi River Commission has a line from the Gulf as far North as Central Iowa, along the Mississippi River. This is soon to be connected with Lake Michigan at Chicago, and a check thus obtained *via* the Great Lakes to sea level at New York City. The writer has been directly connected with some 900 miles of this work and that on the Great Lakes, extending over a period of eight years. In the course of this work every conceivable source of error has been examined, its magnitude investigated, and methods of preventing or eliminating the error advanced. The result is that a remarkable degree of precision has been reached, and much valuable data as to the sources of error obtained.

Before taking up the various sources of error in leveling in detail, it is necessary to distinguish between two classes of errors, viz., compensating errors, or those which tend to balance each other, and cumulative errors, or those which always have the same sign. This distinction is very important. An apparently inappreciable error, if of the latter class, may, in the course of a hundred miles, amount to more than all the larger compensating errors combined.

Take an example: If ten settings are made to the mile, in 100 miles there will be 1,000 settings. If the mean algebraic sum of all the compensating errors for one setting be 0.01 foot the theory of probabilities indicates that the final probable error would be $\sqrt{1000} \times 0.01$ ft. = 0.32 ft.

Whereas, if the mean algebraic sum of the cumulative errors for one setting be 0.001 ft., the final *actual* error from this cause is 1000×0.001 ft. = 1.00 ft.

It may be further remarked, that in

the prosecution of any work where a certain degree of accuracy is required, it is desirable, yes, even necessary, that the director of the work should be cognizant of the nature and importance of all sources of error down to a limit much smaller than that to which he is working. The more thorough and complete his knowledge is in this matter, the more readily and accurately will he be able to decide what sources of error may be wholly neglected, what may be provided against partially, and what must be carefully avoided or eliminated. In other words, his work is planned by an intelligent judgment, instead of by blind guessing. This larger knowledge of the sources of error will be conducive to economy of time and cost for a given degree of precision. The observer comes to see that what before had been carefully attended to at considerable expense may now be neglected, and he can rigidly proportion his pains and labor to the degree of precision required. The most successful and valuable director of any work is always he who does his work just well enough for the needs of the case, making therefore the cost directly proportional to the degree of precision and security sought.

With this preface let us proceed to consider in detail some of the most common sources of error in leveling.

II.—Discussion of Errors.

All possible sources of error in a line of levels may be classified under the following heads: 1. The observers. 2. The instruments. 3. The ground. 4. The atmosphere.

We accordingly have four general classes of errors:

1. Errors of observation. 2. Instrumental errors. 3. Errors from unstable supports. 4. Atmospheric errors.

They will be considered in this order.

1. *Errors of Observation.*—Since no observer is infallible, we may say that these errors are unavoidable, and that our only safety lies in a sure means of detecting and correcting them.

A single observation in leveling consists of two readings, reading the bubble and reading the rod. If the bubble is kept in the middle of the scale, it is no less read. If the instrument has a delicate milled head screw under one wye, the bubble may always be read in the middle, even with a very delicate bubble. If the wye adjustment is made by capstan screws, and the bubble can only be conveniently moved by the lower leveling screws, it is difficult to keep the bubble exactly in the middle. It is then advisable to bring it nearly to the center and read the two ends and correct the reading by the amount it is out. A table of bubble corrections should be provided for this purpose, for various distances of rod and readings of bubble. I believe this to be the largest source of errors of observation, that the bubble is not carefully centered, or that it is not carefully read and the correction applied. Every leveler should know what the error of rod reading is for an inaccuracy of bubble reading of 1 division. This is readily done by taking a known base, running the bubble, say 10 divisions, and noting the corresponding change of rod reading. The observer thus learns how accurately he must read his bubble for a given degree of accuracy in results.

The fact that 1 second of arc gives a tangent of 0.3 inch (0.025 foot) in a mile is a very convenient piece of information. Thus a 25 second bubble gives a movement of 0.05 ft. for a run of 1 division of 400 feet distance. This is the mean value for the two level bubbles in the level in use for students in the Washington University. Delicate levels have bubble tubes that give a run of one division for 2 or 3 seconds of arc.

If a target rod is used, errors of one foot and one-tenth are not uncommon. Such errors are less common with speaking rods. These, and in fact all other errors, are usually sought by duplicating the line. Since, however, the discrepancy in the two lines is the algebraic sum of all the errors committed, it furnishes an unsatisfactory check on any one class of errors. It is advisable, therefore, to obtain a check on each source of error independently.

The best check on errors of reading a target rod is, perhaps, for both rodman and observer to read it independently and compare notes. Let the rodman read it and make a record of it. The observer, on passing the rod, or *vice versa*, reads it also and records it in the note-book. The rodman then calls off his reading and checks.

To avoid errors in reading a speaking rod two or three horizontal wires may be used, a reading taken on each of them, and the mean used as the rod reading. This method is practiced in the levels of precision of Switzerland and it has also been used on the U. S. Lake Survey and under the Mississippi River Commission. It gives excellent results. A speaking rod is much more satisfactory for the observer, the observation is made in less time, and I believe, where the rod is properly graduated, it gives better results than a target rod. I think the spaces in the rod should not be less than 0.02 ft. in width. The precise leveling rods that I have used are graduated to centimeters, and the reading is made to millimeters by estimating the tenths of this space. Three horizontal wires are read. One centimeter is almost exactly $\frac{1}{3}$ of a tenth of a foot. If the graduation is to be in feet, very good results could be obtained by making the smallest graduation $\frac{1}{2}$ of a tenth, and then estimating tenths of this space, bringing the smallest reading to five thousandths. One should not be alarmed at this apparently large limit to our reading error. Because a target reads to thousandths is no evidence that it was set to that limit. Besides, if the reading on the speaking rod is made to the *nearest* tenth of the above space, it is true to $2\frac{1}{2}$ thousandths, and the target is not usually set within this limit.

This reading of three horizontal wires also furnishes an accurate stadia measurement of the length of sight, and thus enables the observer to keep the sum of his back sights equal to the sum of his fore sights, and thus to thoroughly eliminate all instrumental errors.

Not only so, but since these two wire intervals bear a known relation to each other—usually they are nearly equal—if the partial intervals be at once taken out they will show whether or not one wire has been read wrong, and if so, it can be corrected before the instrument has been disturbed. If but two wires are read, this check cannot be obtained and the check is a very valuable one. When so great care is taken, the observer should have a recorder to keep the note-book. If also the bubble is not read in the middle, but correction is made for its displacement, we have a true measure of the length of sight, so that this correction can be applied with great accuracy.

For greater convenience in reading the bubble, it is sometimes set on the top of the telescope as a striding level and provided with a mirror so that the observer can read it with one eye without removing the other from the eye-piece. With this arrangement, and a milled head screw under the wye, the observer can continually watch his bubble and hold it, by touching up the wye adjustment, to any desired reading, preferably to the center.

2. *Instrumental Errors.*—By instrumental errors we mean all errors that enter the work on account of any want of adjustment in the instrument. There are but two sources for this class of errors, viz.: (1) From line of sight not being parallel to the axis of the bubble, and (2) from the rod not being vertical. For, if the line of sight is horizontal, and the rod is vertical, a true difference of elevation may be obtained.

The parallelism of the line of sight and the bubble axis may be examined directly, or through an intermediate plane; directly by means of the "peg adjustment," and indirectly by means of the collimation and inclination. In the former, the instrument is usually set midway between two points and their difference of elevation determined. It is then moved near to one of them, and their difference of elevation again determined. If it is the same as before, the line of sight is horizontal and the adjustment is perfect. If the new difference of elevation is different from the first, the adjustment is made either on the bubble tube or on the collimating screws; that is to say, the bubble is brought to be parallel to the line of collimation, or *vice versa*. A simpler modification of this method is to set the level nearly over the first stake, and, by holding the rod upon it, read height of eye-piece. Then hold rod on distant stake and read. Now move the instrument nearly over the second stake and repeat the operation. If a is the difference of elevation by first set, and b is the difference by second set of readings, the true difference is $\frac{a \times b}{2}$ and the target can be set and line of collimation brought parallel to bubble accordingly. It will be seen that this is on the same

principle as the usual method, only that one of the sights in this case is reduced to zero, and the remaining two are equal.

The more common method, perhaps, for bringing the line of sight to a horizontal position is by making it first coincide with the axis of telescope (centers of rings) by revolving the latter about its axis (collimation), and then making the bubble parallel to the lower side of the rings by reversing the telescope in the wyes (inclination). This is on the principle that two lines that are parallel to a third are parallel to each other. This method does not involve any readings on the rod, and is more rapidly made than the other. All this on the supposition that the adjustment is to be made as nearly as possible, and then called correct, and no further account taken of it. Since it is impossible, however, to do anything exactly, in the best work the values of the residual errors in these adjustments are determined in divisions of bubble (which is seconds of arc) and a final correction made for them.

One marked peculiarity of these errors in leveling is the fact that, provided they are constant, they are wholly eliminated by taking equal back and fore sights. When the greatest possible accuracy is sought, a correction is applied to the difference between the sum of the distances on back sights and the sum of the distances on fore sights. This difference in distance is the residual length of back or fore sight for which the instrumental errors of adjustment remain uncompensated. One adds a great deal to the accuracy of a line of levels by carefully attending to making the back and fore sights on turning-points as nearly exact as possible.

The stability of the instrumental adjustments is greatly increased by keeping the instrument in the shade. A heavy canvas umbrella should be provided, which would thoroughly intercept the sun's rays, which the ordinary alpaca umbrella is by no means able to do.

The value of one division of bubble is also not a constant ordinarily. If the bubble is confined by metallic fastenings, a change of temperature of these will increase or diminish the strain on the bubble, and so change its curvature. If, therefore, the bubble is read out of the center and corrections applied to the rod readings, the value of the bubble should be tested under various temperatures, and if its value changes its fastenings should be examined and so arranged as to relieve it from variable pressure. If the bubble is always read in the middle of the scale, a change in the tube's curvature is of no consequence. I have used rubber bands for fastening bubble tubes in their cases, and they answered very well but need to be renewed every few months. I have known of bubbles changing nearly fifty per cent. of their value from a change of temperature of their metallic fastenings.

A small source of error arises from the sluggishness of the bubble, and the amount it lacks of coming to its true point of equilibrium. If it is very sluggish it is apt to be read before it has stopped moving, and if it stops short of its true center, a small angular error is committed. From theoretical considerations and also from experiments I have made, I conclude, that for a given tube, and within the limits of uniform curvature, the air bubble is sensitive directly in proportion to the square root of its length, and also, that the longer the air bubble the nearer it finally comes to its true center. By sensitiveness, I here mean readiness or quickness in responding to small changes of angle and rapidity in settling to its final position.

The bubble tube should therefore always have an air chamber, so that the length of the air bubble could be adjusted. Then a short bubble need never be used, and there would be a saving of both time and accuracy, inasmuch as the long bubble settles more quickly and more accurately than the short one.

2. The inclination of the rod may be called an instrumental error, or an error of observation. Without some special device, the rodman cannot hold his rod exactly plumb. It is an easy matter to attach a watch level to a rod, which can be adjusted daily by means of a plumb line. The verticality of the rod is sometimes tested by having it waved back and forth, after the target is set, to see if the wire corresponds to its highest position. This is well enough, perhaps, except when the target comes less than about three feet from the bottom of the rod. The error, at this height, in a New York rod used in this way is two thousandths

of a foot, and this error increases fifteen thousandths for a reading of 0.5 ft. on the rod. The error is caused by the front face of the rod being lifted when the rod is revolved backward and rests on its back corner at bottom.

Another small instrumental error is the error in the graduated length of rod. This is a slightly variable quantity, but only affects the total difference of elevation between initial and final points.

In the Coast Survey Precise Levels, * the instrumental constants of collimation and inclination are eliminated by reversing bubble and telescope on each back sight and fore sight, thus making four pointings for each complete reading. Each pointing is of a single wire on a target. The target is set once for the entire set of four readings, and the differential quantities read on a micrometer head attached to the elevating screw under the eye and wye. There are two objections to this method, aside from the labor. First, the target being set but once, there is but one reading for it, and opportunities for error in making this reading do not seem to be sufficiently checked. Second, when the final bisection of target occurs, the bubble is not readable, since this bisection has been made by moving the telescope out of the horizontal by the micrometer screw. The screw was previously read for a central position of bubble, and the bisection made and the screw read again. This is good provided the perfect stability of the instrument can be relied on. It is my experience, that with a 24-lb. instrument, on many kinds of ground, this cannot be done. Much less would I look for stability in a 45-lb. instrument, such as the Coast Survey use. The internal evidence of their published results also goes to show that when all corrections are applied, the four pointings of one reading have discrepancies that can only be satisfactorily explained by supposing the instrument changes between the two micrometer readings of a single pointing. I would therefore prefer a method which would enable me to know the exact direction of the line of sight at the instant when the reading is made.

For a delicate bubble, the changes of temperature in the different parts of the instrument, even when it is in the shade, and the instability of the instrument supports, usually cause the bubble to move almost continually, so that it must be constantly touched up by the wye adjustment while making the rod reading. For this purpose, the great advantage of being able to watch the bubble in a mirror while making the wire readings, is apparent. The accuracy of a pointing depends directly on our ability to know accurately the direction of the line of sight at the instant the reading is taken. This the observer is unable to do in the Coast Survey method.

3. *Errors from Unstable Supports.*—This is a much more important source of error than is generally supposed, inasmuch as it is usually cumulative. If the rod and instrument settle slightly the effect of each is the same and makes the final elevation too high by the total amount of the settling. The converse, of course, is true for a recovery or springing up of supports. If the rod settles between the reading of fore and back sights upon it the back sight readings are too large. If the instrument settles between the reading of a back and fore sight the fore sight reading is too small. The effect of each is the same, viz., to make the final elevation too great. Whether the supports rise or settle depends on the character of the ground and method of setting the tripod and kind of rod support used. In soft ground both rod and instrument may settle. In spongy and clayey grounds, if the tripod legs are forced in too hard they will recover somewhat when the pressure is removed, and if the rod is supported on a peg or pin it may spring up some also. I think, however, that the discrepancies caused by a rising of supports come mainly from the instrument rather than the rod. In very sandy ground or in pure sand a pin used for rod support is apt to settle or be lowered by the slight impact of setting the rod upon it if it is not of considerable size. A foot-plate of some 18 or 20 square inches is a better rod support in sand and in hard solid roadways than a pin, while the latter is preferable in clayey grounds.

If we assume a settling of supports the final result is too high by the total amount of the settling. If the line be run in the opposite direction, what is

* See Report of U. S. Coast and Geodetic Survey 1879.

now the initial point, as computed from what is now the final point, is too low by the total amount of settling. The mean of the two lines has this error eliminated, and the discrepancy between the two measures the total settling on the two lines. If, in a long series of stretches, duplicated in the opposite direction, the discrepancies are mostly of one sign, we are forced to conclude that some such action has occurred. If the line had been duplicated in the same direction this error would not show in the discrepancy, so that the check would be closer, but the actual error in the mean much greater than if duplicated in the opposite direction. The only method of eliminating this set of errors is, therefore, to duplicate the line in the opposite direction and take the mean.

Although these errors are very small if considered singly, they are cumulative, and become important if long distances are run without eliminating them.

The fact that when lines were duplicated in opposite directions the discrepancies tended to one sign has been often discussed, and various reasons assigned,* such as personal equation, illumination of target, etc., but I think it is all explained by the instability of supports. In so far as different observers would more or less effectually overcome these errors by their methods of setting rods and instruments, in just so far may it be called personal. It is not personal in the sense that it is in the reading of the rods or in the setting of the targets. If it were it would affect back and fore sights alike and would not appear in the difference between these readings, which is really the observed quantity.

4. *Atmospheric Errors.*—Errors from this source may be classified as coming from (1) Wind, (2) Tremulousness, (3) Variable Refraction.

(1.) Wind generally shakes the instrument and makes the holding of the rod difficult or impossible. For two seasons I have used a tent on windy days to protect the instrument, and with great success. Good work can be done in this way so long as the rod can be held. We also have large square canvas umbrellas that can be set on the ground to the windward of the instrument, and these effectually shield them in ordinary windy weather.

The tents used were wall-tents, 5×6 feet, and one 8-foot center pole. A square iron frame, $3 \times 3\frac{1}{2}$ feet, sewed into the canvas near the top, formed the lateral support there. It was held down by six or eight steel pins, 18 inches long and $\frac{1}{2}$ inch diameter, with flat heads. These passed through iron rings sewed into the bottom. There were openings for the line of sight and a flap for the observer to enter and pass out with the instrument. These tents were made to be used on Gulf coast at a very windy season, when one-half the time would have been lost from high winds without them. The rodmen supported their rods by sticks held in the hand and braced against the rod at an angle, resting on the ground. Care had to be exercised that the rods were not thereby lifted from their sockets in the foot plates.

(2.) Tremulousness is caused by a difference of temperature between air and ground, and always occurs in clear weather after the sun is a few hours high. This causes the target, or figures on a speaking rod, to appear to move up and down, giving rise to what is known as "dancing" or "boiling." This simply causes an uncertainty in the reading, depending directly on the degree of unsteadiness. It is a compensating error, and the observer must be his own judge as to when he must stop work in order to obtain the required degree of precision. The only remedy is to shorten the length of sight, but as there are some errors that multiply directly with the number of sights taken in a given distance, there is also a limit to which this remedy may be profitably carried. I do not think it advisable to use sights less than 100 feet if the highest accuracy is sought, and perhaps never more than 400 feet, even when the atmosphere is perfectly clear and steady. In clear weather not more than 3 or 4 hours a day can be utilized for the best work.

(3.) Variable refraction occurs when the sunshine suddenly comes upon or leaves the line. This happens along the edge of timber or under the brow of a hill, as when the line rapidly emerges from or comes into the shade, from the sun's movement, or on partially cloudy

*Acknowledged in Coast Survey Report 1879, p. 208, to be not, as yet, satisfactorily explained.

days, when the sun is alternately covered and clear. When from the first source, it occurs about 8 A. M. and 4 P. M. It is a peculiar phenomenon, and is more common in winter than in summer. The atmosphere is apparently steady and the sight well taken, but, upon checking it, the reading has changed, and may be observed to change gradually or suddenly, and sometimes to recover a part or all of its original movement, when the instruments were known to be stable. I have seen these changes of reading amount to 5 millimeters, or $\frac{1}{5}$ of an inch in a distance of 100 meters, or 328 feet. If the atmosphere is found to be in this condition, the work should be stopped for a while, as this state of affairs is not likely to continue long.

III.—Conclusion.

We have now considered about all the legitimate sources of error in leveling. Such errors as arise from setting on the wrong turning point, disturbing of turning point, slipping of target, holding rod wrong end up, etc., are due to accident or carelessness, and need not be mentioned.

With good instruments and with proper care and attention to all sources of error, a single instrument ought to be able to duplicate 30 miles of line a month with a wye level and a target rod, and bring all discrepancies within five hundredths of a foot into the square root of the distance in miles; or with the U. S. Precise Levels and speaking rods, reading three horizontal wires, one instrument should do the same work, bringing all discrepancies within two hundredths of a foot into the square root of the distance in miles. For the last 400 miles of Mississippi River Precise Levels with which I have been connected, about nine-tenths of the work has checked within a limit of 12 thousandths of a foot into the square root of the distance in miles, and the last 200 miles was done at the rate of 30 miles of completed duplicate line a month for a single instrument. The cost of this field-work, including one complete field reduction and the setting of permanent bench marks every 3 miles, was about $18 per mile of completed line.

The limit for the discrepancies between duplicate lines of levels under the Commission is 21 thousandths of a foot into the square root of distance in miles. On the Coast Survey it is 30 thousandths of a foot into the square root of the distance in miles, being respectively expressed by the following formula in terms of millimeters and kilometers:

Commission's limit, $d = 5^{mm} \sqrt{k}$

Coast Survey's " $d = 5^{mm} \sqrt{2k}$.

Magnetic Elements for 1882.—From the report of the Astronomer Royal to the Board of Visitors of the Royal Observatory, Greenwich, the principal results for magnetic elements for 1882 were as follows:

Approximate mean Westerly declination (or variation) 18° 22′.

Mean horizontal force { 3.913 (in English units). 1.804 (in metric units).

Mean dip { 67° 33′ 33″ (by 9-in. needles). 67 34 34 (by 6-in. needles). 67 34 14 (by 3-in. needles).

—*Nautical Magazine.*

In their monthly report on the London water supplied by the companies during March, Mr. William Crookes, F. R. S., Dr. Wm. Odling and Dr. C. Meymott Tidy, say: "In respect to the proportion of organic matter, as indicated by the determinations of organic carbon, it is interesting to compare the results afforded by the past months analyses with those obtained before and during the recent period of quite exceptional river floods. Confining attention to the five companies taking their supply exclusively from the Thames, the average amount of organic carbon during the past month was 0.152 part in 100,000 parts of water; the average during the month of October, when the influence of the floods began to be felt, being 0.158 part. The average for the four months, preceding October and the floods, was 0.117 part; while the average for the four succeeding months, when the floods were at their highest, was 0.244 part—this last and highest average, corresponding to less than half a grain of organic matter per gallon of water, with a maximum in any individual sample, out of the sixty-eight averaged, falling short of three-quarters of a grain."

THE GASKILL PUMPING ENGINE AT SARATOGA, N. Y.

By JOHN W. HILL, M. E.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE many inquiries from engineers and others interested in pumping machinery for public water supply, upon points not included in the official report upon the performance of the Gaskill Compound Pumping Engine at Saratoga, is the principal apology for this paper.

The duty developed upon contract trial, charging the engine with all coal, burned, with no allowance for unburnt coal, ash, or clinker, or water entrained in the steam, was nearly 113,000,000 foot pounds. A duty which stands without a parallel, capacity and cost of engine considered.

The engine is horizontal, of the rotative beam, non-receiver, compound type, and involves several novel features of construction, whereby a large capacity and a high economy is obtained by a simple machine in a small compass.

The contractor's specification describes an engine containing four steam cylinders arranged in pairs, one high-pressure and one low-pressure cylinder to each pair, with the high-pressure cylinder mounted axially over the low-pressure cylinder.

Each pair of steam pistons drives one pump, the rod of which is connected direct to the cross-head of the low-pressure piston, and by means of the beam and system of short links with the high-pressure piston.

The main shaft common to both pairs of steam pistons turns in two heavy pillow blocks, mounted one on each pump-discharge chamber, between which the fly-wheel revolves. The ends of the shaft are provided with overhung cranks and pins set at quarters to receive the outer ends of the two shackle bars, the inner ends of which are strapped to the upper pins of the beam.

The pumps are of the double-acting plunger variety, packed with an internal gland which is adjusted by means of bolts passing through the rear pump heads. Each plunger is driven by a single rod.

The steam cylinders are all jacketed sides and heads, the condensation from which is trapped back to the boilers.

The air pumps are worked by a double arm, keyed to the inner end of each of the two beam shafts.

The steam valves are of the double-beat poppet style, the intermediate valves and exhaust valves to the low-pressure cylinders are gridiron slides.

The steam valves are adjustable at the will of the engineer, but the intermediate and exhaust valves have a fixed action relative to motion of piston. All the valves are driven by eccentrics, mounted upon two longitudinal shafts turning in bearings sprung from the inner sides of high-pressure cylinders.

These shafts are driven by miter wheels from the main shaft.

The receiving and discharge valves of the pumps are of rubber, working on metal stems and seats, small in diameter and numerous in quantity.

The entire engine is compactly massed upon a heavy horizontal bed-plate, to which the beam housings and steam and water cylinders are neatly and firmly attached.

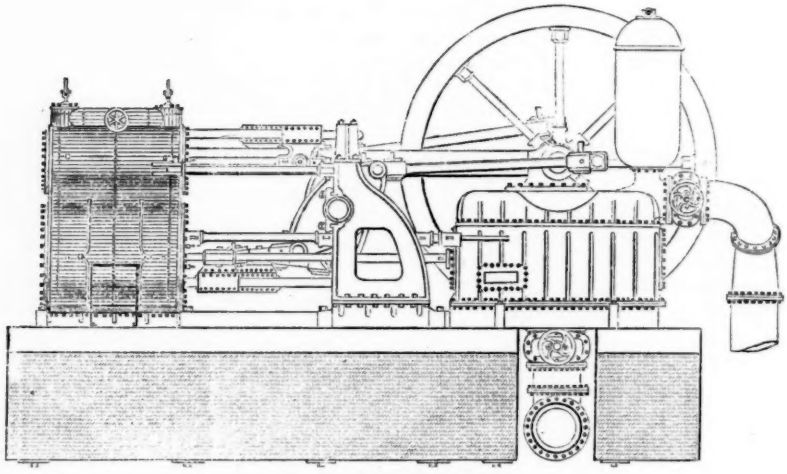
The engravings of the engine, which are kindly furnished by the Holly Manufacturing Company to illustrate this article, are drawn to scale, and correctly represent all the principal details of this celebrated machine.

The following dimensions of engine are taken from the contractor's specification, excepting measurements of pump plungers and strokes, which were made by the writer directly the contract trial was completed:

High-pressure cylinders (2), diam.	21 inches
High-pressure piston rods (2), diam.	3 "
High-pressure pistons, stroke.	36 "
Low " cylinders (2), diam.	42 "
" " piston rods (4), diam	3.5 "
Low-pressure pistons, stroke.	36 "
Clearance high-pressure cylinder.	2.35 per cent.
" low " "	2.50 " "

Pump plungers (2), diam	20 inches
" plunger rods (2), diam....	4 "
" plungers, stroke.....	36 "
Fly-wheel, diam	12.33 feet
" " weight.....	12,000 lbs.
Main shaft, diam.....	10 inches

The boilers furnishing steam to the engine are two in number, of the horizontal return tubular variety, and are each of the following dimensions:



SIDE ELEVATION OF ENGINE.

Diameter of shell.....	65 inches
Length of shell.....	18 feet
Number of tubes.....	87
Diameter of tubes, outside.....	3 inches
Grate length.....	57 "
" width.....	72 "
Heating surface, both boilers....	2957.5 sq. ft.
Grate " " "	57 " "
Ratio heating to grate surface...	51.89
" grate surface to cross section of tubes.....	8.717

The contract requirements of engine were a "pumping capacity of four millions United States gallons in twenty-four hours, working at eighteen revolutions per minute against a pressure of eighty pounds per square inch, and the plant to develop a duty the equivalent of eighty million pounds of water raised one foot high, with a consumption of one hundred pounds of best coal."

By the terms of the contract under which the machinery was furnished, the builder had the privilege of selecting the coal to be burned, and the election of the pressures by steam and water gauges, and revolutions of engine, for the duty trial.

The Water Board of Saratoga had the option of the time and duration of duty trial.

The Water Board selected the writer, and the contractor selected Professor D. M. Greene, of Troy, N. Y., to conduct and report the trial, the results of which are recorded in this paper.

The town of Saratoga Springs is supplied with water for all purposes upon the direct service system, the water being pumped from a collecting reservoir, known as Loughberry Lake, directly into the distributing mains. After canvassing several doubtful methods of measuring the delivery of the pumps without cutting off the force main (a proposition which, for diplomatic reasons, could not be entertained by the Water Board), it was finally deemed sufficient to carefully measure the diameter and stroke of plungers, and from this data and the revolutions of engine during the trial, with such an allowance for slip or loss of action as was justified by precedent, to estimate the delivery of pumps.

The displacement of two plungers, each 21 inches diameter and 36 inches stroke, with a single rod 4 inches diameter for each revolution of the engine, in United States standard gallons, is 191.923.

Which quantity, reduced by a proper allowance for loss of action (with packing rings and valves tight under pressure), represents the approximate actual delivery of pumps.

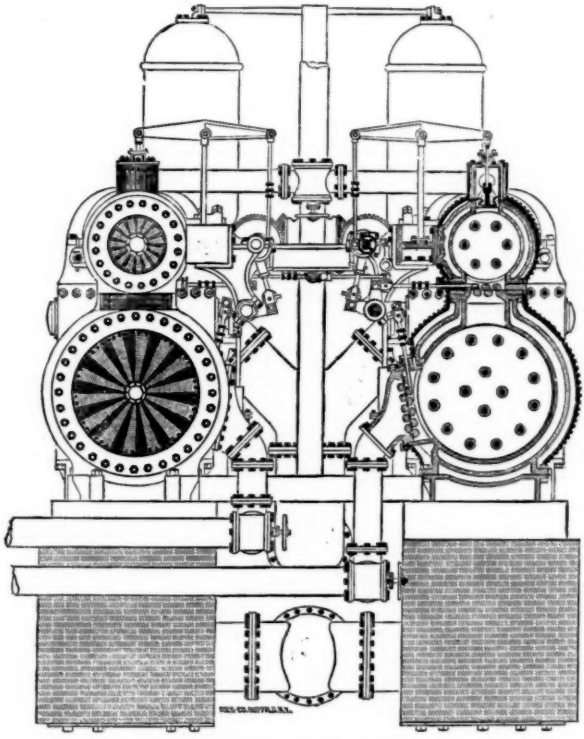
The pumps, four in number, of the Gaskill Compound Pumping Engine, built by the Holly Manufacturing Company for the water-supply of Memphis, Tenn., were substantially similar to the pumps of the Saratoga engine, and showed upon measurement by reservoir a delivery of 97.57 and 97.56 per cent. of the plunger displacement.

Adopting 97.5 per cent. as the coefficient of delivery for the pumps of this engine, then the actual daily discharge for eighteen revolutions per minute is $191.923 \times .975 \times 18 \times 60 \times 24 = 4{,}850{,}280$ gallons per diem of 24 hours.

The contract calls for a delivery of 4,000,000 gallons, whence the probable actual delivery is

$$\frac{4{,}850{,}280 - 4{,}000{,}000}{4{,}000{,}000} \times 100 = 21.257$$

per cent. in excess of contractor's guarantee.



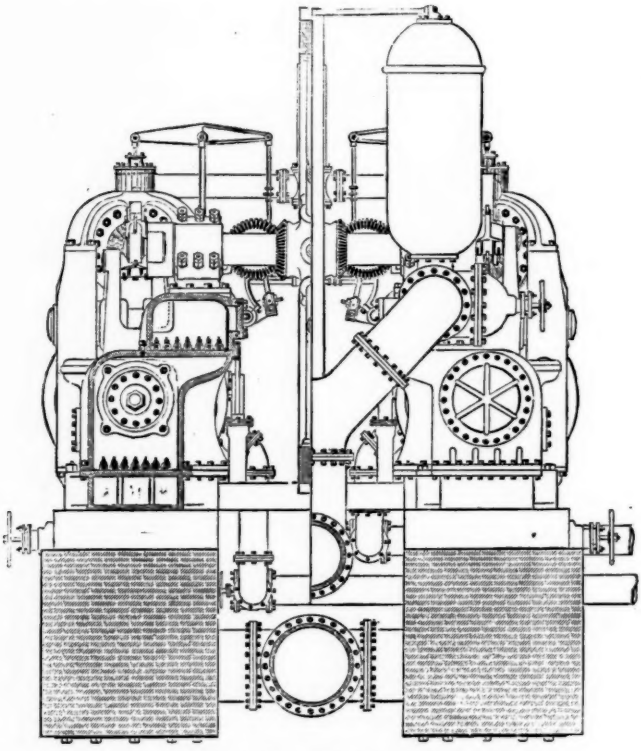
ELEVATION STEAM END.

Assuming, however, the very liberal slip of *five* per cent., then the excess of delivery over contractor's guarantee was nearly 726,000 gallons per diem—a margin sufficient to cover any possible error of judgment in estimating the capacity from pump dimensions and speed.

The contract provided for a delivery of "4,000,000 gallons per diem, against a domestic pressure of 80 pounds per square inch." During the duty trial of twenty hours, the engine made an average of 17.8742 revolutions per minute, pumping against an average pressure of

95.07 pounds by gauge, which was equivalent to a delivery per diem, under contract pressure, with an allowance of 2.5 per cent. for loss of action, of

$$\frac{17.8742 \times 95.07}{80} \times 187.125 \times 60 \times 24 =$$



ELEVATION WATER END.

5,723,667 gallons, or an excess of capacity above contractor's guarantee of

$$\frac{1,723,667}{4,000,000} \times 100 = 43.09 \text{ per cent.}$$

And yet it seems there are people in Saratoga who do not believe that this engine is capable of pumping 4,000,000 gallons of water against 80 pounds pressure at any speed.

The duty trial began at 8 A. M., Nov. 1, 1883, and terminated at 4 A. M., Nov. 2, covering an unbroken run of twenty hours, during which time, at regular intervals, observations were made of the engine counter, steam and water pressure gauges, water levels in boilers, temperatures of injection, overflow, water to heater and feed water to boilers, meter in feed pipe, and vacuum gauge.

The coal burned was "Lackawana" of excellent quality, as shown by the remarkably small percentage of refuse during the trial. This was weighed in double charges of 150 pounds each, and dumped into the coal wagon in front of the boilers; each charge to the boilers of 300 pounds was exhausted before the next charge was permitted in the wagon.

Indicator diagrams from all the steam cylinders were taken at irregular intervals during the trial.

From the log of trial are obtained the following averages and totals as affecting the duty:

DATA FROM DUTY TRIAL.

Engine counter at 8.00 A.M., Nov. 1st.	286,053
" " " 4.00 " " 2d.	307,502
Revolutions for 20 hours	21,449
Average pressure by water gauge	95.06875
" " " engine steam gauge	74.25
Average vacuum by gauge	27.295
" temperature of injection	56.225
" " " overflow	71.125
Total coal burned (pounds)	6,750

From which data we deduce the duty as follows: First, by the generally adopted method of

$$D=\frac{A\times P\times F\times 100}{C}$$

Where A represents the mean area of one plunger at right angles to its axis, P represents the total pressure per square inch of plunger, and consists, first, of the observed pressure by gauge, + or − difference of levels (center of water pressure gauge and source of supply) + an allowance for extra frictional resistances of water passages into and out of pumps, usually taken at one pound; and F represents the total plunger travel during trial, in feet. C represents the coal burned during trial. The condition of fires being alike at beginning and end of trial, with minimum fluctuations of steam pressure and water levels in boilers; and second, as a net or absolute duty by the method

$$D=\frac{G\times W\times H\times 100}{C}$$

Where G represents the actual delivery of water during trial in United States standard gallons, W the weight of water at observed temperature per gallon, and H the head in feet through which the water is pumped, consisting of the algebraic sum of the head due pressure by gauge, and the difference of levels (center of water pressure gauge and source of supply), C, as before, represents the total coal burned during trial.

Calculating duty by first method,

$$A=\frac{20^2\times .7854+(20^1\times .7854-4^2\times .7854)}{2}$$

$$=307.8768 \text{ sq. ins.}$$

P=pressure by gauge mean of 81 readings	95.06875
Difference of levels, center of water pressure gauge and source of supply $\frac{2.3}{2.3}\frac{0}{0}\frac{8}{5}$	0.09965
Allowance for extra frictional resistance of water passage into and out of pumps	1.0000
	96.1684 lbs.
F=revolutions during trial	21,449
Piston travel per revolution	12
	257.388 feet
C=total coal burned	6,750 lbs.

Then by formula,

$$\frac{307.8768\times 96.1684\times 257,388\times 100}{6,750}$$

$$=112,899,983.104$$

foot pounds duty, or the work of raising nearly *one hundred and thirteen million pounds of water one foot high*, without frictional resistance or loss of effect.

The contract provides for a duty of eighty millions, which is exceeded by the duty based upon the conventional formula by 41.125 *per cent.*

Calculating the duty by second method:

G=191.923×.975×21,449=	4,013,642.516 gals.
W=weight per gallon taken for temp. 56	8.33 lbs.
H=pressure by gauge (95.06875×2.308)	219.418
Difference of levels, center of gauge and source of supply	0.230
	219.648 feet.
C=total coal burned	6,750 lbs.

Then by formula,

$$\frac{4,013,642.516\times 8.33\times 219.648\times 100}{6,750}$$

$$=108,793,535.3$$

million pounds of water raised one foot high as the equivalent of absolute duty.

The contract provides for a duty of eighty millions, which is exceeded by the net duty, *nearly* 36 *per cent.*

In the following table are recapitulated the averages of all data and totals for duty trial:

Duration of trial hours	20
Average pressure by engine gauge, pounds	74.25
Average vacuum, inches	27.295
" temperature of injection, Fahr.	56.225
Average temperature of overflow, Fahr.	71.125
Average temperature of feed-water to boilers	169.175
Average pressure by gauge on force-main, pounds	95.06875
Difference of levels, center of pressure gauge and source of supply, pounds	0.09965

Revolutions in 20 hours.....	21,449
Revolutions per minute.....	17.8742
Piston speed per minute, feet..	107.2452
Total coal burned, pounds....	6,750
Calculated discharge of pumps per revolution, gals...	191.923
Actual estimated discharge of pumps per revolution, gals..	187.125
Weight of water per gallon at 56 F., pounds.....	8.33
Contract delivery at 18 revolutions, gals...	4,000,000
Actual estimated delivery at 18 revolutions, gals.....	4,850,280
Excess over contractor's guarantee, per cent..... .	21.257
Contract duty per 100 lbs., coal	80,000,000
Conventional duty as per trial..	112,899,983.104
Excess over contractor's guarantee, per cent..... .	41.125
Net absolute duty as per trial..	108,793,535.3
Excess over contractor's guarantee, per cent.....	36

As a matter of interest to the Water Board and others, arrangements were made to determine the economy of the boilers during the duty trial, with the following result:

Duration of trial, hours.....	20
Average pressure by gauge, pounds	76.644
Average temperature of feed-water.	169.175
Average temperature of water to meter.....	85.575
Average percentage of water entrained.....	6.273
Water by meter record, cubic feet..	1181.8
Error of meter record, percentage..	2.8457
Weight of water per cubic foot, (temp. 85.575) pounds.... ...	62.135
Weight of water passed through meter, pounds....	75,520.773
Weight of water drawn off for temperature of feed, pounds.....	214.0
Weight of water to boilers, pounds.	75,306.773
Weight of water entrained, pounds.	4,723.994
Weight of net steam, pounds.....	70,582.779
Weight of coal burned, pounds.....	6,750
Steam per pound of coal from temperature of feed, pounds.....	10.4567
Steam per pound of coal from and at 212, pounds.....	11.286
Weight of ash and clinker returned, pounds....	216.0
Percentage of non-combustible . . .	3.2
Coal burned per square foot of grate surface per hour, pounds.....	5.833
Steam per square foot of heating surface per hour, pounds.....	1.1933

The specification for the engine provides for "air pumps" to remove the air, water of condensation, and condensing water from "jet condensers," to be worked from the engine shaft. In place of which the contractor has substituted the now well-known Bulkley condensing apparatus. The merit of this change must be measured by the results. The vacuum obtained ranges from 27 to 28 inches, and the engine power, which, with air pumps, would be absorbed in discharging the contents of the condensers, is now utilized in forcing water into the mains.

Whatever gain in economy of performance was obtained by the change in condensing apparatus is a benefit alike to the contractor in his increased duty upon trial, and a continuous benefit to the water service to the extent of the power which otherwise would be required to work the air pumps.

Barring an unevenness of some bearings (which a limited use and proper attention to working joints will soon remedy), the performance of the engine was very satisfactory.

There was a defect in the cut-off valve motion of the left engine, to which the contractor's attention was called, and which he promised to correct. When corrected, the present hesitation of the engine in turning the right inboard center will disappear.

The following schedule contains the rate at which the fuel was consumed during the trial:

Date.	Time.	Coal charged.	Coal burned.	Pound per min.
Nov. 1.	800 A. M.	300	——	——
	8:56 "	300	300	5.357
	10:03 "	300	600	4.478
	10:51 "	300	900	6.250
	11:35 "	300	1200	6.818
	12:48 P. M.	300	1500	4.110
	1:59 "	300	1800	4.225
	2:47 "	300	2100	6.250
	3:20 "	300	2400	9.091
	4:13 "	300	2700	5.263
	5:11 "	300	3000	5.085
	6:03 "	300	3300	5.769
	6:43 "	300	3600	7.500
	7:53 "	300	3900	4.286
	8:48 "	300	4200	5.454
	9:33 "	300	4500	6.666
	10:31 "	300	4800	5.172
	11:32 "	300	5100	4.918
Nov. 2.	12:23 A. M.	300	5400	5.882
	1:17 "	300	5700	5.555
	2:02 "	300	6000	6.666
	2:51 "	300	6300	6.122
	3:23 "	150	6600	9.375
	4:00 "	——	6750	4.054
Average.....				5.625

Coal burned first	five hours.....	1550.7	lbs.
" " second	" "	1732.0	"
" " third	" "	1659.93	"
" " last	" "	1807.37	"
		6750.00	

The mean water pressure, or head pumped against, including difference of levels and allowance of one pound for friction, for the several intervals of five hours each, was,

For first five hours.....	95.874
" second " "	96.900
" third " "	97.075
" last " "	94 824

And the corresponding revolutions of engine was,

For first five hours	5305
" second " "	5587
" third " "	5396
" last " "	5161

The duty varies directly as the head pumped against, as the revolutions of engine, and inversely as the coal burned, or by equation

$$D' = D \frac{p'r'c}{prc'}$$

where D=duty for whole trial.
p=mean head pumped against for whole trial.
r=revolutions for whole trial.
c=coal burned for whole trial.
p'=head pumped against for any interval of trial.
r'=revolutions for same interval.
c'=coal burned " " "
and D'=duty for same interval.

Whence the duties have been calculated approximately for the several intervals of trial as follows:

For first five hours.....	121	millions
" second " "	115	"
" third " "	116	"
" last " "	100	"
For whole trial approximately	113	"

While the duties for the several intervals are not as reliable as the duty calculated for whole trial, the method adopted in handling the coal was such as to furnish fair approximations at any stage of the test.

The writer gauged the fires carefully at beginning of trial, at end of trial, and frequently during the trial, to determine how faithfully the injunction was observed by the fireman and assistant in charge of the coal, to so employ the fuel that as each barrow was exhausted the original depth of fire should be restored. In brief, the fires were not to be diminished from the condition subsisting when trial began.

The writer and Professor Greene sat in the boiler room during the intervals between observations, with an assistant in constant attendance upon the coal scale and barrow, and every charge of coal was reported for time and quantity directly it was weighed up.

The final charge of 150 pounds of coal at 3:23 A. M. was recorded against the protest of the contractor, upon demand of the writer, in order that any error in restoring the original depth of fire should count against, rather than in favor of, the engine, and an examination of the schedule of coal fired will demonstrate that the final charge of 150 pounds might have been omitted with an increase in the duty, and without disturbing the previously established rate of coal consumption.

The mean rate of coal consumption per hour, for the first eighteen hours and fifty-one minutes, by the record was 334.2 pounds, and for entire trial, omitting final charge of 150 pounds, 330 pounds per hour, including final charge of 150 pounds, 337.50 pounds, and for last hour and nine minutes of trial, at the rate of 391.3 pounds per hour.

The mean steam pressure by boiler gauge was, at commencement of trial, 65 pounds, at end of trial 80 pounds, and as a mean for whole trial, 76.644 pounds; and mean water pressure upon pumps exclusive of difference of levels (source of supply and pressure gauge) and allowance for frictional resistance, was, at commencement of trial, 90 pounds, at end of trial 94.5 pounds, and as a mean for whole trial 95.068 pounds, from which it appears that the steam pressure was raised during 20 hours of trial from 65 to 80 pounds, whilst operating against a mean resistance of 95.068 pounds upon water pressure gauge, or an accumulating resistance from 90 to 94.5 pounds, with an increase in the revolutions of engine of last hour over first hour of trial, as follows:

Revolutions first hour.....	1026
" last "	1040
" mean for 20 hours..	1072.45

The furnaces were in excellent shape, and the boilers cleaned a few days prior to the trial, and no known change in any portion of the plant calculated to affect the duty occurred during the trial, and the diminution of duty during the last interval of five hours can only be accounted for by a more lavish expenditure

of coal upon the part of the contractor, and the special charge of 150 pounds during last hour of trial, to restore the original thickness of fires, which the writer thought at the time and still believes *might* have been omitted without prejudice to the interests of the Water Board, but which was added upon his demand in order that the error, if any, in restoring the fires should be calculated to diminish rather than increase the duty.

Omitting the last charge of 150 pounds of coal the duty for the 20 hours was 115½ millions, which more nearly represents the scientific duty of the engine than the one officially reported.

FRONT END, RIGHT ENGINE.

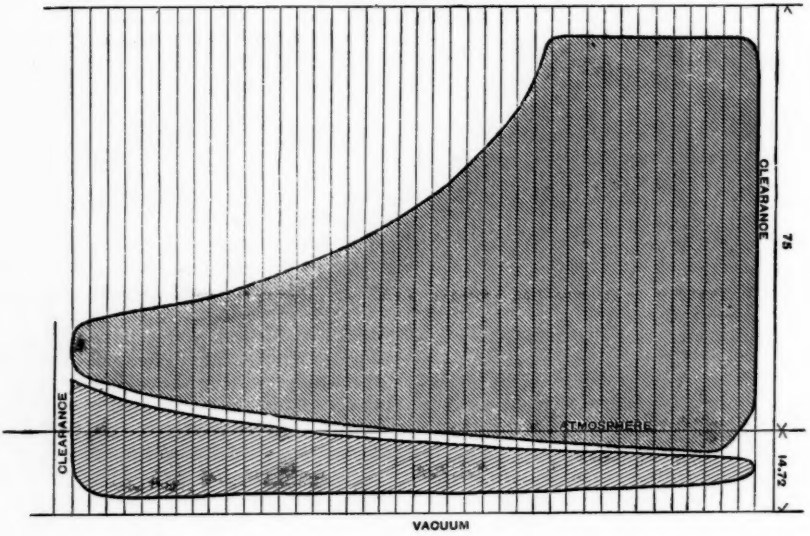
Piston displacement, high-pressure cylinder	7.0686 cu. ft.
Clearance	0.1661 "
Volume	7.2347 "
Cut-off in decimal of stroke, including clearance	0.3136
Exhaust closure in decimal of return stroke, including clearance	0.9282
Piston displacement, low-pressure cylinder	28.4625 cu. ft.
Clearance	0.7115 "
Volume	29.1740 "
Release in decimal of stroke, including clearance	0.9854
Expansion by volumes	12.906

BACK END, RIGHT ENGINE.

Piston displacement, high-pressure cylinder	7.2158 cu. ft.
Clearance	0.1696 "
Volume	7.3854 "
Cut-off in decimal of stroke including clearance	0.3039
Exhaust closure in decimal of return stroke	0.9282
Piston displacement, low-pressure cylinder	28.8633 cu. ft.
Clearance	0.7215 "
Volume	29.5849 "
Release in decimal of stroke, including clearance	0.9927
Expansion by volumes	13.333
Mean expansion by volumes	13.119
" " " pressures	10.161*

FRONT END RIGHT ENGINE.

BOILER PRESSURE.



The cuts are true copies of the diagrams taken at 12:10 P. M., Nov. 1st, from right engine reduced from 40 spring for high-pressure cylinder, and 12 spring for low-pressure cylinder, to a scale of 30 pounds per vertical inch for both cylinders. The upper diagrams are from the back end of cylinders, and the lower diagrams from the front or stuffing box end of cylinders, the condensing effect of the two low-pressure piston rods being

* The cylinders were jacketed, and the steam contained at least, by weight, *six* per cent. of water entrained, the evaporation of which, after cut-off in the high-pressure cylinders, and during expansion in the low-pressure cylinders, accounts for the smaller grade of expansion by pressures. With dry or slightly superheated steam the approximation of expansions by volumes and pressures would have been much closer.

plainly shown by the increased drop of pressure between the two cylinders.

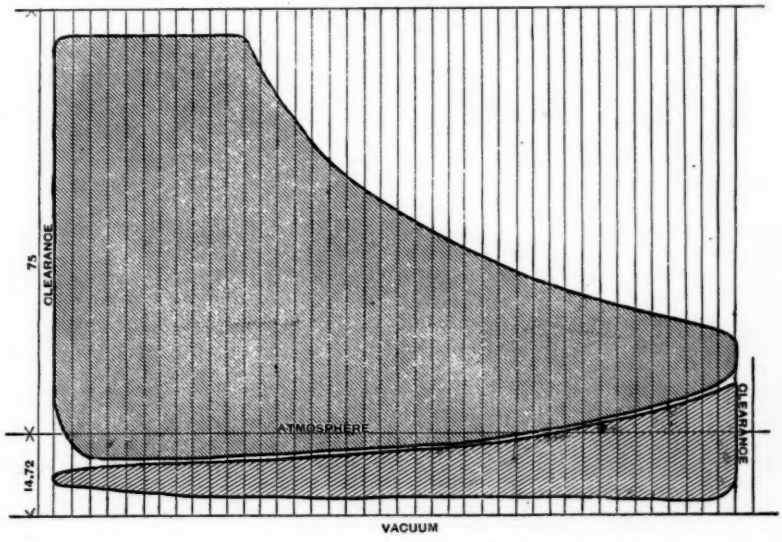
The diagrams have not been criticised for defects of port and valve design, but it is safe to assert that no serious defects could be found in the light of the exalted duty obtained.

The diagrams were taken irregularly, and are too few in number to be accepted as exponents of power and steam consumption, but for what they are worth the data from them are given in the following table:

Low-pressure cylinder mean terminal pressure, absolute	8.574
Low-pressure cylinder mean counter-pressure at commencement of return stroke, absolute	6.574
Low-pressure cylinder mean counter-pressure at end of return stroke, absolute	2.338
Vacuum realized in cylinders, pounds / inches	12.382 / 25.122
Factor of horse-power high-pressure cylinder, front	1.1027
Factor of horse-power high-pressure cylinder, back	1.1256
Factor of horse-power low-pressure cylinder, front	4.4400

BACK END RIGHT ENGINE.

BOILER PRESSURE.



DATA FROM DIAGRAMS.

High-pressure cylinder mean effective pressure, front	47.38
High-pressure cylinder mean effective pressure, back	52.211
High-pressure cylinder mean inititial pressure	72.146
High-pressure cylinder mean terminal pressure	21.389
High-pressure cylinder mean counter-pressure at commencement of return stroke, absolute	25.31
High-pressure cylinder mean counter-pressure at end of return stroke, absolute	9.692
Low-pressure cylinder mean effective pressure, front	9.4025
Low-pressure cylinder mean effective pressure, back	9.9988
Low-pressure cylinder mean initial pressure, absolute	23.942
Low-pressure cylinder mean terminal pressure, absolute	8.574
Low-pressure cylinder mean counter-pressure at commencement of return stroke, absolute	6.574
Low-pressure cylinder mean counter-pressure at end of return stroke, absolute	2.338
Vacuum realized in cylinders, pounds / inches	12.382 / 25.122
Factor of horse-power high-pressure cylinder, front	1.1027
Factor of horse-power high-pressure cylinder, back	1.1256
Factor of horse-power low-pressure cylinder, front	4.4400
Factor of horse-power low-pressure cylinder, back	4.5025
Total horse-power developed	197.7823
Caal per indicated horse-power per hour	1.7064
Duty of engine based on total work	116,033,755

Comparing the duties of steam and water ends of engine, it appears that of the total power developed, 97.3 per cent. was utilized in forcing water into the mains. The thermal value of a pound of pure carbon is 14,500 British units, and the percentage of carbon in the coal burned was fairly 96.8, from which the mechanical equivalent of heat per H. P. of engine was, $1.7064 \times .968 \times 14{,}500 \times 772 = 18{,}490{,}195$, and the efficiency of engine

$$\frac{1,980,000}{18,490,195}=.10708.$$

Had the writer, previous to the contract trial, suspected such a remarkable duty as was developed, the arrangements for indicator diagrams and other data upon which to discuss the exact scientific performance of the engine would have been more elaborate and complete; as it is, he can only rest with the hope that other engines of this type may come under his observation in the future, when an effort will be made to omit no inquiry bearing upon the scientific value of the machine.

CORROSION OF IRON AND STEEL.

By M. L. GRUNER.

Translated from Annales des Mines for VAN NOSTRAND'S ENGINEERING MAGAZINE.

II.

III.—*Action of Acidulated Water.*

We will pass now to the consideration of the experiments with acidulated water without exposure to the air.

In the first experiment, which was of three days' duration, the bath contained one half per cent. of concentrated acid, and was renewed every morning because the action ceased after six hours' time; at least there was no visible disengagement of hydrogen. At the end of the experiment one quarter per cent. of acid was added to favor the cleansing.

The results obtained from the 5th to the 8th of April at Saint Montan are exhibited in Table F, next column.

It is seen that the tempered steel is more strongly attacked than the untempered. Comparing Nos. 5, 6 and 7 of the Verdié steels with the first four of the same series, we find the acidulated water acts upon the high steels more energetically than upon the low ones. The ordinary manganese steel of Saint Montan, especially the hardened plate, is more corroded than the purer steels of Firminy.

Finally the compact and pure cast iron of Ruelle is oxidized much less than Nos. 1 and 3. The manganese specimen proving an exception.

It would seem that the crystalline condition, or rather the intimate combination with carbon, protects the manganese iron against the action of the acid. This is remarkable since sea water attacks manganese iron more strongly than the other cast irons.

TABLE F.

Origin of plates.	No.	Original weight.	Final weight.	Loss.	Remarks.
		gr.	gr.	gr.	
Annealed steel from Verdié forge.	1	242.3	242.0	0.3	All the steel covered with a thin, black coating.
	2	263.8	263.7	0.1	
	3	265.8	265.4	0.4	
	4	280.6	280.0	0.6	
	5	262.5	261.8	0.7	
	6	294.6	293.5	1.1	
	7	270.7	269.9	0.8	
Steel from St. Montan containing manganese and silicon.	*	363.6	362.0	1.6	Thin, black coating.
	†	367.0	362.9	4.1	Thick coating with a strong odor.
Black pig iron from St. Montan.	1	311.6	295.7	15.9	No. 1 was vigorously attacked & was covered with a graphitic coating, thick and odorous.
Charcoal iron.	2	336.0	335.2	0.8	
Gray cast iron.	3	391.3	382.4	8.9	
Manganese iron of St. Montan.	‡	723.4	721.9	1.5	

* Soft. † Tempered. ‡ White crystalline.

The following experiments exhibit still further the resistance of the white crystalline iron to the action of acidulated water. From the 17th to the 27th of July the same plates were exposed to water containing $\frac{1}{2}$ per cent. of concentrated acid which was renewed twice; first on the 19th and again on the 21st of July.

TABLE G.

Origin of plates.	No.	Original weight.	Final weight.	Loss.	Remarks.
		gr.	gr.	gr.	
Annealed steel from Verdié forge	1	236.0	234 8	1.2	All the plates were well cleaned.
	2	257.4	256.8	0 6	
	3	258.8	258.0	0.8	
	4	273.2	272.5	0.7	
	5	255.1	253 9	1.2	
	6	286.3	285.3	1.0	
	7	263.2	262.0	1.2	
St. Montan steel containing manganese and silicon.	*	356.2	354 2	2.0	
	†	356.1	350.8	5 3	Covered with a black coating.
Black pig iron from St. Montan.	1	289.6	280.4	9 2	No. 1 briskly attacked.
Charcoal pig from Ruelle.	2	329.9	326.9	3.0	
Gray pot metal.	3	377.5	371 7	5.8	
Specular iron of St. Montan.	‡	720.0	719.0	1.0	

* Soft. † Tempered. ‡ White crystalline.

This experiment like the preceding shows that the ordinary steel of Saint Montan is more strongly affected than the pure steels of Firminy (Verdié), and that among the latter the higher carbonized steels are the more sensitive to the action of acid.

We see also that tempering favors the action of the acid. It seems at first singular when comparing this experiment with the preceding, that the irons are relatively less attacked and the steels more. This is explained by the slightly different conditions of the experiments.

Although the second experiment lasted ten days and the first but three. the proportion of acid was made a little higher in the first experiment by the additional ¼ per cent. put in to facilitate cleaning the plates. In the twelve liters employed in the two experiments there were 70 grams of acid consumed in the first against 60 grams in the second trial. By reason of the longer time in the second experiment, the air became an oxidizing agent as well as the acid. Now as moist air oxidizes steel nearly as well as iron, we can understand how in the former experiments (Table C) there was a less difference between the irons and steels than in the experiment F where the action was nearly all due to the acid.

The steels of Unieux (Holtzer) were also subjected to the action of acidulated water without exposure to the air. The experiment continued seven days. The proportion of acid was 2-5 grams for 4 liters (a little more than ½ per cent.) and the bath was renewed after the third day. Table H exhibits the results:

TABLE H.

Origin of plates.	No.	Original wt.	Final wt.	Loss.	Remarks.
		gr.	gr.	gr.	
Annealed steel from Holtzer works	1	301.9	300.5	1.4	Thin covering of black rust.
	2	326.1	324.4	1.7	
	2a	334.7	331.9	2.8	
	3	305.8	304.2	1.6	
	4	322 8	320.8	2.0	
	5	341.8	338.5	3.3	The chrome steel had a thick gray coating.
	6	340.3	339.0	1.3	
Tempered steel. Holtzer.	1	315.7	313.9	1.8	The black deposit is thicker on the tempered plates.
	3	293.3	291.1	2.1	
	4	329.7	326.5	3.2	
	5	335.9	333.2	2.7	
Mild steel of Montlucon	1	148.9	148.0	0.9	
	2	161.9	161.4	0.7	
High steel of St. Montan	1	284.5	282.2	2.3	
	2	360.0	357.5	2.5	

This experiment confirms the results exhibited by tables E and G. We see that the soft steels of Montlucon are as susceptible as the hard and manganese steels of Saint Montan; that the soft chrome steel oxidizes more readily in the air than the others. Furthermore, that in the air the simple carbon steels are more oxidizable when tempered. but Chrome steel is somewhat protected by tempering.

By comparing this experiment with Table B, we see that although acidulated water oxidized soft steels less than hard ones, the action of moist air is only slightly modified by the degree of purity

or percentage of carbon; excepting always chrome steel.

From these tables and from comparisons made with the results obtained by English engineers, we conclude that the action of sea water or acidulated water upon iron differs from that of moist air; and that consequently experiments made with acidulated water teach us nothing of the prolonged action of moist air or salt water. To avoid error we will reconsider separately the results furnished by the experiments.

1st. *Action of Moist Air.*—Tables A, B, C and D prove that all the steels, high or low, except chrome steel, are corroded to the same extent by moist air; that the cast irons resist better than the steels, and the white crystalline *spiegel* iron better than the gray irons.

Chromium favors the corrosion of annealed steel while tungsten produces a contrary effect.

Tables B and D seem to establish the fact that tempering invites rust. In order to test this question a longer test is necessary, for in the two cases referred to, acidulated water played too important a part to enable us to state definitely that tempering favors rusting in moist air alone.

The experiments of M. R. Mallet, in which the specimens were exposed two years to the moist air of Dublin, confirm the above conclusions. The cast iron specimens resisting rust better than wrought iron or steel; the gray cast iron two or three times, and the white cast iron five or six times as well.

Between the irons and the steels on the whole there was not much difference; the latter when tempered resisting a little better than the wrought iron.

M. Parker subjected several kinds of wrought-iron plate and bar to the smoky atmosphere of London for 455 consecutive days. These experiments also proved that all the varieties rust to about the same degree, the commonest bar iron resisting a little better than the best Lowmoor, and the latter a little better than soft cast iron holding $\frac{1}{4}$ to $\frac{1}{2}$ per cent. of manganese.

The English Admiralty and Mr. Phillips have continued the experiments with pure water and with sea water.

2d. *Action of Sea Water.* — The Tables E and E′ exhibit the effect of sea water. These effects are to some extent the reverse of those of moist air. Thus the irons are more strongly attacked than the steels, and among the irons the manganese specimen is most corroded—twice as much as the gray or black iron from the same work. The common iron for pots, and containing phosphorus, is rusted twice as much as the purer charcoal iron from Ruelle. (Table E.)

Tables E and E′ prove also that sea water attacks tempered steel less strongly than untempered, and that the presence of manganese favors the corrosion of steel plates. Apart from this, the action of sea water is about the same for all degrees of carbonization.

The results of M. Mallet's experiments are quite in accord with the above; proving also that wrought iron and steel are affected to about the same degree by salt water, but the steel contrary to the writer's observation was corroded more than cast iron. This difference is probably due partly to the greater amount of manganese in our specimens, and partly also to the circumstance mentioned by Mr. Parker, that M. Mallet's cast-iron plates were used in rough condition, as they came from the foundry, while the wrought iron and steel specimens were previously prepared as in our experiments.

With regard to the amount of oxidation of wrought iron and steel in salt water, it appears, according to Mallet, a little less than that due to moist air during the same length of time, and on the other hand it is nine times as great as that of fresh water.

It is well to observe, however, that the action of the air varies with the season and the climate, and the action of water varies with the depth below the surface. It is observed by iron ship builders that the iron plates are most corroded along the water line; that the parts that are alternately wet by the sea and exposed to the air corrode much faster than those constantly immersed. An analogous fact is observed in steam boilers. The corrosion is most rapid where the feed water is constantly brought in contact, holding air freshly dissolved.

Messrs. Parker and Phillips have studied the action of sea water upon ships' plates and the action of distilled water upon steam boilers. The experi-

ments were chiefly upon wrought iron and mild cast steel. Their results accord with ours and with the observation of the English constructors, proving that there is no sensible difference between wrought iron and low steel in resisting corrosion when used for hulls of ships or in steam boilers using distilled water. In the meantime it seems that water, like moist air, acts upon mild steel a little more readily than upon Lowmoor iron or common wrought iron, but the difference is not more than 5 or 6 per cent. at the most. Notwithstanding this slight inferiority, steel is preferred for purposes of construction by reason of its greater strength and superior homogeneousness. One precaution is indispensable. It is important to scour the plates before using them, otherwise the isolated patches of oxide on the surface tend by setting up a galvanic action to excite corrosion on places not protected by oxide. The action of such spots of rust is nearly as deleterious as a copper plate riveted to the iron. The strip of zinc sometimes employed as a galvanic protector will not entirely neutralize the deleterious influence of patches of oxide.

3d. *Action of Acidulated Water.* — This is chiefly remarkable from the fact that unlike sea water it attacks high steels and impure steels more strongly than the low steels, and tempered more than the untempered steels. It is important therefore to avoid the use of acid even for cleaning metal that is designed for experiments in moist atmosphere. It is liable to vitiate the results as was before remarked in regard to the experiments reported in Tables B, C and D.

The presence of chromium favors corrosion by acidulated water as it also does by moist air and sea water. As to the action of acidulated water upon cast iron, it varies with the compactness of the metal and elements combined with it. The graphitic gray irons are speedily acted upon, while the white crystalline castings resist much better than steel. In a general way the acidulated water acts differently from moist air or sea water. No conclusion about the oxidizing action of moist air or sea water can be fairly reached by experiments made with acidulated water. A conclusion has been wrongly based on M. Adamson's experiments to the effect that moist air tended to corrode hard steel rails more rapidly. In fact these experiments teach us nothing about the wear of rails. Prolonged trials are necessary of exposure to a moist atmosphere before we can pronounce upon the results.

While waiting for such experiences, it seems necessary to admit that the experiments of Messrs. Mallet and Parker teach that the hardness of steel seems to have little influence upon its corrosiveness under the action of moist air. Notwithstanding this it is quite evident that if rails are found to wear faster in tunnels than outside, it is especially due to the moist heat which favors rusting.

4th. *Experiments of M. Brustlein, Director of the Unieux Forges.*—There remains to be given as complementary to the writer's experiments, a report of some interesting analogous studies by M. Brustlein, Director of the Unieux Works.

This engineer sought to determine the influence of manganese upon the properties of steel. He cast three ingots of steel holding six thousandths of carbon, and respectively 1.737—1.188 and 0.434 per cent. of manganese.

It was at once established that the density and rigidity increased with the amount of manganese. Some small bars tried under a hammer took a deflection not quite in proportion to the percentage of manganese. The bending was relatively least for the higher proportions. Some other bars of 13 millimeters diameter and 100 millimeters length between the heads, when tried under a tensile strain, exhibited the following results:

Per ct. of manganese	Elastic limit.	Breaking weight.	Elongation.	Diam. at fracture.	Remarks.
p. 100.	kilog.	kilog.	p. 100.	milm.	
1.737	48.9	88.2	17.0	9.6	Black fibrous, but clear at center.
1.188	44.8	78.2	18.6	9.5	
0.434	39.4	66.8	22.4	9.6	Gray fibrous.

Two sets of bars from the same three ingots were suspended, one set in the flue of a Galloway boiler, and the other in the water of the same boiler at a distance from the feed-water inlet. The experiment continued 112 days. The weight in both sets remained sensibly the same; but the set from the flue were slightly coated with magnetic oxide, while those

from the boiler were covered with a brown muddy deposit of 1 to 2 millimeters thickness, under which appeared a black carbonaceous coating similar to that which appears on steel when attacked by acidulated water. The bars were then subjected to tensile strain with the annexed results.

Bars in flue.	Elastic limit.	Breaking weight.	Elongation.	Diam. at fracture.	Remarks.
Per ct. mn.	kilog.	kilog.	p. 100.	milm.	
1.737	41.8	69.4	16.2	8.8	Dark gray; fibrous.
1.188	38.0	64.7	21.3	8.7	
0.434	30.7	58.7	13.7	9.3	Gray; fibrous.

Bars in water.	Elastic limit.	Breaking weight.	Elongation.	Diam. at fracture.	Remarks.
Per ct. mn.	kilog.	kilog.	p. 100.	milm.	
1.737	44.8	80.2	15.3	9.4	Dark gray; fibrous.
1.188	40.1	73.5	15.7	10.8	
0.434	32.1	63.4	14.0	10.7	Gray; granular.

We see that the metal was acted upon in the water as well as in the smoke flue, and the steel suffered more than the manganese; it has become less ductile and granular.

This is a point that boiler makers would do well to note; that steel plates lose in time a part of their tenacity and flexibility.

M. Brustlein has also determined that acidulated water dissolves most actively the metal that contains most manganese. But we cannot conclude from what we have previously determined that fresh water in boilers would act in the same way. Meanwhile, since manganese, according to the preceding experiments, favors the action of either fresh or salt water upon steel, it may be considered as not the less established that as little manganese as possible should be permitted in plates for steam boilers or hulls of ships.

VARIOUS METHODS OF DETERMINING DIMENSIONS.

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Selected Papers of the Institution of Civil Engineers.

I.

In a former paper, the author promised subsequently to give a short demonstration and comparison of those methods of determining dimensions, based on the assumption of a variable strength, which have recently been proposed. This review it is intended to give in the present paper. The development of each method must of course be confined to the essential ideas involved. For purposes of ready comparison this will be followed by the determination of the limiting stresses per unit of sectional area allowed by each, and, in conclusion, a number of examples and tables will be given. Some of the methods shown have obtained a footing in practice, others contain valuable ideas for further development, and all are of interest as steps forward on the road towards a rational method of determining dimensions. When it is once recognized that the strength of materials has not the same value in all the various circumstances in which the loads are applied, a method different to that hitherto used must gain ground. Those who cannot approve any of the proposed methods will, perhaps, by a knowledge of them, be stimulated to achieve something better.

The general points of view explained in I. to IV. of the author's former paper will be assumed as known, and the nomenclature and notation there introduced maintained. Hence t denotes the *statical breaking strength* per unit of area (developed by a static load once applied), u the *primitive strength* (breaking strength for stress of one sense alternating with zero), s the *vibration strength* (strength developed by oscillations, where there is an alternation of stresses of equal intensity in opposite senses), a the *ultimate working strength* (the breaking strength under the particular circumstances of loading), d the differ-

ence of the limiting stresses, and b the admissible stress; the word stress being an abbreviation for "intensity of stress," unless otherwise indicated.

For the sectional area F, let φ denote the ratio of the numerically smaller to the numerically greater limit of stress (φ being positive when both are tensile, negative when one is tensile and the other compressive, φ_0 the ratio of the stress produced by the fixed or "dead" load, if any, to the numerically greater limit of stress, and B_0, B_1 and B_2 the numerical values (without signs positive or negative) of the fixed load,* and the two limiting values of the variable or "live" load.

Then there follows for tension only or compression only, if max. B and min. B denote the numerical values of the upper and lower limits of total load,

$$\varphi=\frac{\min B}{\max B} \qquad \varphi_0=\frac{B_0}{\max B} \quad . \quad . \quad . \quad (1)$$

and for alterations of tension and compression, when max B and max B′ denote the values of the numerically greater and smaller limiting total loads respectively,

$$\varphi=-\frac{\max B'}{\max B} \quad \varphi_0=\pm\frac{B_0}{\max B} \quad . \quad . \quad . \quad (2)$$

In the latter expression the upper or lower sign is to be taken according as the dead load produces stress of the same or opposite sense as the upper limit of live load.

If the admissible stress b be known, then

$$F=\frac{\max B}{b}, \quad . \quad . \quad . \quad . \quad . \quad (3)$$

as in equation (2) of the former paper.

Where in the sequel numerical values occur, the stresses b are given in kilograms per square centimeter, the values of F in square centimeters.

I. Gerber's Method.

The first work on the admissible stresses for iron and steel based on Wöhler's experiments, was written by Gerber, the manager of the South German Bridge-building Establishment, in 1872, adopted by the Bavarian Government, and published in 1874.†

Every piece of a square unit of sectional area would be destroyed by a static load producing stress of intensity $=t$. The same result may be attained by a load constant only as to one portion c, and as to the other d acting by numerous temporary repetitions; hence the difference of stress d is equivalent to a certain static load τd, and there follows

$$(a) \qquad c+\tau d=t=\delta d,$$

where δ denotes a coefficient, determined by the preceding equation.

If for a piece of any section F, the static calculation give a fixed load, B_e and a limiting value B_v of the live load, then these loads might by means of the equation

$$(b) \qquad B_e+\tau B_v=B_r=\delta B_v$$

be reduced to a static load, if only τ or δ were known, and the requisite section would then be found by

$$(c) \qquad F=\frac{B_r}{b_r}$$

where b_r is the admissible stress per unit of area for a static load.

The hypothetical loads B_r Gerber calls "reduced forces."

As Wöhler has determined the statical breaking strength t for certain materials, and also the possible differences of stress d for various initial stresses c, by substituting these special values c, d, t, in the above equation, the corresponding values of the coefficients τ, δ may be at once ascertained. τ and δ will of course vary, not irregularly, but continuously with the ratio

$$(d) \qquad \varphi=\frac{c}{d}=\frac{B_e}{B_v}.$$

In order to express the law according to which this variation takes place, Gerber makes $x=\frac{c}{t}$, $y=\frac{d}{t}$, assumes the curve determined by x and y, having regard to the numerical values obtained by Wöhler, to be a parabola, and thus gets relations, by means of which δ, and therewith also

$$(e) \qquad \tau=\delta-\varphi$$

may be determined. In general, if δ denote a constant depending on the nature of the material,

$$(f) \quad \delta=\tfrac{1}{2}(\delta+\sqrt{\delta^2+4\varphi^2+4\varphi+1}) \quad . \quad (4)$$

* "Load," as in the former paper, means the total amount of the external force, tensile or compressive as the case may be, applied to the single bar or piece under consideration.

† Gerber, "Bestimmung der zulässigen Spannungen in Eisenconstructionen."

The values of δ can be previously calculated for regularly progressive values of φ and tabulated, as done by Gerber.

In all formulas B_e and B_v are to be substituted with their signs (tension positive, compression negative), so that Φ becomes positive or negative according as B_e, B_v, have similar or opposite signs. If the straining force B_v due to the "live" load* act in the contrary sense to that due to the "dead" load, the total force may become $B_e+B_v=0$, in which case $\varphi=-1$. The values of B_r always have the same sign as B_e+B_v.

The practical application of the preceding method Gerber make as follows:

In order to take into account vibrations and impact, for the live load B_v, is substituted n times that quantity, and then

$$\varphi=\frac{B_e}{nB_v} \quad . \quad . \quad . \quad . \quad (5)$$

For this value of φ, δ is determined by (4), and there results

$$B_r=n\delta B_v \quad . \quad . \quad . \quad . \quad (6)$$

$$F=\frac{B_r}{b_r}=\frac{n\delta B_v}{b_r} \quad . \quad . \quad . \quad . \quad (7)$$

Gerber chooses for iron $\delta=1.5$, $n=1.5$, for structures in which lightness is the principal requisite and small alterations of form are no disadvantage, $b_r=2{,}400$, and for structures in which the greatest possible durability is required, $b_r=1{,}600$ kilograms per square centimeter. Hence, for the latter

$$\varphi=\frac{B_e}{1.5\,B_v} \quad . \quad . \quad . \quad (8)$$

$$\delta=\tfrac{1}{2}(3+\sqrt{16\,\varphi^2+16\,\varphi+13}) \quad . \quad . \quad (9)$$

$$F=\frac{1.5\,\delta\,B_v}{1{,}600} \text{ square centimeters} \quad . \quad . \quad (10)$$

If the moving load may become positive as well as negative, φ, δ, F must be calculated for both limiting values B_v separately, and the sum of the numerical values $F=F_1+F_2$ gives the actual sectional area.

The object now is to express the stress per unit of area allowed by Gerber.

If a piece be subjected to tension only or compression only, then minimum $B \leqq B_0$.

$$\left.\begin{aligned}\varphi_1&=\frac{B_0}{n(\max B-B_0)}F_1\\&=\frac{n\,\delta_1}{b_r}\,(\max B-B_0)\;.\;.\\ \varphi_2&=\frac{B_0}{n(B_0-\min B)}F_2\\&=\frac{n\,\delta_2}{b_r}\,(B_0-\min B)\;.\;.\end{aligned}\right\} \quad (11)$$

From this follows the resultant maximum stress per unit of area

$$\left.\begin{aligned}b&=\frac{\max B}{F_1+F_2}=\frac{1}{\delta_1(1-\varphi_0)+\delta_2(\varphi_0-\varphi)}\,\frac{b_r}{n}\\ &\text{where with (1)}\\ &\delta_1 \text{ from (4) corresponds to}\\ &\qquad\varphi_1=\frac{\varphi_0}{n\,(1-\varphi_0)} \quad . \quad . \quad .\\ &\delta_2 \text{ from (4) corresponds to}\\ &\qquad\varphi_2=-\frac{\varphi_0}{n\,(\varphi_0-\varphi)} \quad . \quad . \quad .\end{aligned}\right\} \quad (12)$$

If in a special case the fixed load coincides with one of the limiting loads, then either $\varphi_0=\varphi$, $F_2=0$, or $\varphi_0=1$, $F_1=0$, and from (12)

$$\left.\begin{aligned}b&=\frac{1}{\delta\,(1-\varphi)}\,\frac{b_r}{n} \quad . \quad . \quad . \quad .\\ &\text{where with help of (1)}\\ &\text{for } B_0=\min B, \text{ from (4) corresponds to } \varphi=\frac{\varphi}{n(1-\varphi)}\\ &\text{for } B_0=\max B, \delta \text{ from (4) corresponds to } \varphi=-\frac{1}{n(1-\varphi)}\end{aligned}\right\} \quad (13)$$

If, on the other hand, a piece has to sustain alterations of tension and compression, there follows, according as the fixed load (numerical value B_0) has the same or the opposite sign as the higher limiting load (numerical value max. B) with the upper or lower sign,

$$\varphi_1=\frac{\pm B_0}{n\,(\max B\mp B_0)};\quad F_1=\frac{n\,\delta_1}{b_r}(\max B\mp B_0)$$

$$\varphi_2=\frac{\mp B_0}{n\,(\max B'\pm B_0}};\quad F_2=\frac{n\,\delta_2}{b_r}(\max B'\pm B_0)$$

The greatest stress per unit of sectional area now amounts to

* In the sequel the straining force due to the live load will be called simply the "live load," and that produced by the "dead" load the "fixed load," these terms referring to the forces applied to a single piece, and not to the *weight* on the structure of which the piece forms a part.

$$b=\frac{\max B}{F_1+F_2}=\frac{1}{\delta_1(1-\varphi_0)+\delta_2(\varphi_0-\varphi)}\cdot\frac{b_r}{n}$$

where with (2)

δ_1 from (4) corresponds to

$$\varphi_1=\frac{\varphi_0}{n\,(1-\varphi_0)}$$

δ_2 from (4) corresponds to

$$\varphi_2=\frac{\varphi_0}{n(\varphi-\varphi_0)}$$

(14)

When in a special case the permanent load coincides with one of the limiting loads, either $\varphi_0=\varphi$, $F_2=0$, or $\varphi_0=1$, $F_1=0$, but by (14)

$$b=\frac{1}{\delta(1-\Phi)}\,\frac{b_r}{n}\quad\ldots\ldots$$

where by (2)

for $B_0=\max B'$, δ from (4)

corresponds to $\varphi=\dfrac{\varphi}{n(1-\varphi)}$

for $B_0=\max B$, δ from (4)

corresponds to $\varphi=-\dfrac{1}{n(1-\varphi)}$

(15)

For iron structures of the greatest possible durability the values $n=1.5$, $b_r=1{,}600$ would have to be substituted, in which case equation (4) merges into (9).

II. Schaffer's Modification.

In Gerber's method, the way in which he proceeds in the case of the live load having different signs, provokes criticism, particularly with regard to such structural parts as are subjected alternately to tension and compression. The calculation is made as though there were two pieces, instead of taking into account the whole difference of stress at once in accordance with Wöhler's law. This drawback Professor Schaffer, of the Darmstadt Polytechnic, has avoided by a modification of Gerber's method. His first work on this subject appeared in 1874, and was supplemented by subsequent papers.*

Schaffer, in developing his theory, reversing Gerber's method, makes $x=\frac{d}{t}$, $y=\frac{c}{t}$; and recognizing Gerber's conclusions, with regard to the relation between x and y, puts the latter into a somewhat different form by introducing

$$(a)\qquad \xi=\frac{d}{a},$$

a denoting the ultimate working strength. For this latter the following general expression results

$$a=\frac{-\delta\xi+\sqrt{\delta^2\xi^2+(2-\xi)^2}}{(2-\xi)^2}\,2t\quad\ldots\quad(16)$$

where δ is the same constant, dependent on the nature of the material, used by Gerber.

The numerical values of the limiting straining forces resulting from the moving load only, producing tension solely or compression solely (min $B\leqq B_0$), are expressed as follows:

$$B_1=\max B-B_0\quad\ldots\ldots\quad(17)$$

$$B_2=B_0-\min B\quad\ldots\ldots\quad(18)$$

and for alternate tension and compression (max $B'\leqq$ max B)

$$B_1=\max B\mp B_0\quad\ldots\ldots\quad(19)$$

$$B_2=\max B'\pm B_0\quad\ldots\ldots\quad(20)$$

In the latter case the upper or lower sign is to be used according as the fixed load (numerical value B_0) is of the same or opposite sense as the higher limiting load (numerical value max B).

As the difference of load for the whole section with tension or compression only is max B − min B, and for alternate tension and compression max B + max B', there follows with reference to (a) generally

$$(b)\qquad \xi=\frac{d}{a}=\frac{B_1+B_2}{B_1\pm B_0};$$

this value must of course always be positive.

If the ultimate working strength a corresponding to the preceding value of ξ is to be determined, and the unit of area of the section subjected to this stress, the limit of destruction would just be attained without the action of impact and vibrations. In order to take the latter into account, Schaffer introduces all forces resulting from the moving load into the calculation multiplied with a factor n, even in determining ξ, and for further safety only the m^{th} part of the hypothetical working strength corresponding to this value of ξ is used in the calcula-

* Schäffer. "Bestimmung der zulässigen Beanspruckung für Eisenconstructionen." Zeitschrift für Bauwesen, 1874. Deutsche Bauzeitung, 1875, 1876.

tions. The determination of the sectional area then takes the following form:

From the static calculation is determined

$$\xi=\frac{n(B_1+B_2)}{nB_1\pm B_0} \quad . \quad . \quad (21)$$

where B_0 has the upper or lower sign prefixed according as it corresponds to a load in a similar or an opposite sense to max B. Then equation (16) gives the hypothetical working strength a, and the sectional area becomes

$$F=\frac{m}{a}(nB_1\pm B_0) \quad . \quad . \quad . \quad (22)$$

Like Gerber, Schaffer adopts for iron the values $\delta=1.5$, $n=1.5$, and for permanent structures $\frac{t}{m}=b_r=1{,}600$, so that

$$\xi=\frac{1.5\,(B_1+B_2)}{1.5\,B_1\pm B_0} \quad . \quad . \quad . \quad (23)$$

$$\frac{a}{m}=\frac{-3\xi+\sqrt{13\,\xi^2-16\xi+16}}{(2-\xi)^2}1{,}600 \quad . \quad (24)$$

$$F=\frac{m}{a}(1.5\,B_1\pm B_0) \quad . \quad . \quad . \quad (25)$$

For $\xi=2$, formula (24) gives $\frac{a}{m}=\frac{0}{0}$; the determination of the value of this expression leads to the result $\frac{a}{m}=534$.

Schaffer's equations must give the same results as Gerber's when the fixed load coincides with one of the limiting loads, because in that case Gerber's division into two pieces does not enter into the calculation. Schaffer has also demonstrated how by his method liability to buckling may be taken into account.

With the help of equations (17)–(20), and (1) (2), there follows from (21) (22)

$$\xi=\frac{n(1-\varphi)}{n-(n-1)\varphi_0} \quad . \quad . \quad . \quad (26)$$

$$F=\frac{m}{a}\,(n\max B\mp(n-1)B_0),$$

and hence the admissible stress per unit of area

$$b=\frac{\max B}{F}=\frac{1}{n-(n-1)\varphi_0}\frac{a}{m} \quad . \quad (27)$$

Here—in accordance with (26) $\frac{a}{m}$ by (16) $-\varphi$, and φ_0 are determined in the case of tension or compression only, from equation (1), and for alternate tension and compression by (2)

In particular for permanent iron structures

$$\xi=\frac{3(1-\varphi)}{3-\varphi_0} \quad . \quad . \quad . \quad . \quad (28)$$

$$b=\frac{2}{3-\varphi_0}\frac{a}{m} \quad . \quad . \quad . \quad . \quad (29)$$

III.—Muller's Suggestion.

Mr. Müller, a Viennese engineer, published in 1873 an essay on the "Determination of Dimensions." He starts from the assumption that every stress exceeding the limit of elasticity, that is, accompanied by a permanent alteration of form (set), must, if repeated sufficiently often, produce fracture. The primitive strength u, as the smallest stress in one sense which can practically cause fracture, is identical with the usual limit of elasticity. With smaller differences of stress, or larger values of $\frac{c}{d}$—notation as under I.—Fracture can only be brought about by the greater working stress a; hence there exist, according to the ratio $\frac{c}{d}$ an infinite number of limits of elasticity, varying from u to the statical breaking strength t.

If all values of c assumed by Wöhler be represented as abscissæ (tension positive, compression negative), and the corresponding values of a, determined experimentally, as ordinates, a curve is obtained which Müller prolongs until it intersects the c-axis, arriving by means of analogies, which, however, are not precisely defined, at the value of the primitive strength for compression, and thus completing Wöhler's data. From this curve it would be possible for every given value

$$(a) \qquad \varphi=\frac{c}{d}=\frac{B_c}{B_v},$$

to determine the working strength a, and allowing a suitable factor of safety the admissible stress b.

Müller considers a factor of safety of 3 as suitable, but intends when using the value $b=\frac{a}{3}$ to take into account the in-

* G. Müller, "Zulässige Inanspruchnahme des Schmiedeisens bei Brücken constructionen."

fluence of temperature and corrosion separately in previously determining a.

The influence of a rise of temperature is taken as equivalent to the stress which would produce the same extension.

It is stated that the influences of temperature and load are fortunately not altogether cumulative, but that each takes a separate part in the wear and tear, and "this circumstance clearly tends to reduce the absolute maximum stress with a large permanent load, because when stresses due to other causes come into action, the danger of reaching the absolute limit of fracture is increased."

In accordance with this the ratio $\beta = \frac{a}{u}$ is modified in a way not quite clear, and determined for a series of values of φ from the completed curve representing Wöhler's results, whence

$$(b) \qquad b = \tfrac{1}{3}\,\beta\,u.$$

Here Müller makes $u = 1{,}600$, and calculates accordingly two tables of admissible stresses, one for tension alone, and one for alternations of tension and compression.

It is easy to perceive that in the preceding method untenable assumptions are included. It is by no means the case that everything tends to show that a single increase of temperature "exerts exactly the same influence on a member of a bridge as a single application of a load"; but, on the contrary, experience hitherto has been opposed to this. It has been observed that at temperatures of 100° to 200° Centigrade equal and greater loads are carried than at ordinary temperatures, although both influences, which are supposed to act in the same sense, are cumulative. Neither can the choice of a primitive strength for compression, which exceeds that for tension, in the total absence of experiments in this direction, be approved.

IV.—Winkler's Method.

In the year 1877 Dr. Winkler, Professor at the Polytechnic of Berlin, published a method of determining dimensions,* which may be briefly described as follows.

* E. Winkler, "Wahl der zulässigen Beanspruchung für Eisenconstructionen."

If for given values $\pm a'$ of the numerically smaller limiting stress per unit of area as abscissas, the corresponding values of the working strength a be plotted as ordinates in accordance with Wöhler's experiments, Winkler finds that when a represents a tensile stress, the ends of the latter are grouped sufficiently closely about a straight line to justify the equation.

$$(a) \qquad a = u \pm \alpha\, a'.$$

This formula is temporarily assumed to be applicable for compression also, so that generally speaking the upper or lower sign is to be taken before a', according as the latter value represents a stress in a similar or opposite sense to a.

With a static load $a = a' = t$, therefore

$$(b) \qquad t = u + \alpha t \quad u = (1-\alpha)t.$$

$$(c) \qquad a = (1-\alpha)t \pm \alpha\, a'.$$

Assuming a factor of safety m, the admissible stress is $\frac{a}{m}$; hence if temporarily B_g represent the numerical value of the numerically smaller limiting load,

$$(d) \qquad F = \frac{m.\max B}{a} = \frac{m.B_g}{a'}.$$

From this equation there follows, with reference to the preceding,

$$(e) \qquad \max B = \frac{1-\alpha}{m} F t \pm \alpha B_g,$$

and if the static stress admissible with a factor of safety m be again denoted by $\frac{t}{m} = b_r$, then

$$(f) \qquad F = \frac{\max B \mp \alpha.B_g}{(1-\alpha)b_r},$$

here the upper or lower sign must be taken according as the smaller limiting load is of the same kind as (numerical value $B_g = \min B$) or opposite to (numerical value $B_g = \max B'$) the greater. By substitution of the values min B and max B from (17)–(20) there follows generally

$$(g)\ F = \pm\frac{B_0}{b_r} + \frac{B_1}{(1-\alpha)b_r} + \frac{\alpha B_2}{(1-\alpha)b_r}.$$

In order to take account of impact and vibrations, Winkler introduces the live load multiplied by n into the calculation, whence

$$F = \pm\frac{B_0}{b_r} + \left[\frac{B_1}{(1-\alpha)b_r} + \frac{\alpha B_2}{(1-\alpha)b_r}\right] n. \quad (30)$$

When max B denotes tension, Winkler makes $b_r = 1{,}400$, $a = 45$, and, after rounding off the results, obtains for structures not subject to impact and with $n=1$,

$$F = \pm\frac{B_0}{1{,}400} + \frac{B_1}{770} + \frac{B_2}{1{,}700} \quad . \quad . \quad (31)$$

for railway bridges, with $n=1.3$,

$$F = \pm\frac{B_0}{1{,}400} + \frac{B_1}{590} + \frac{B_2}{1{,}300} \quad . \quad . \quad (32)$$

for road bridges, with $n=1.2$,

$$F = \pm\frac{B_0}{1{,}400} + \frac{B_1}{640} + \frac{B_2}{1{,}400} \quad . \quad . \quad (33)$$

When, however, max B denotes compression, the values should be $b_r = 1{,}200$, $a=0.40$, so that then, for structures not subject to impact with $n=1$,

$$F = \pm\frac{B_0}{1{,}200} + \frac{B_1}{720} + \frac{B_2}{1{,}800} \quad . \quad . \quad (34)$$

for railway bridges, with $n=1.3$,

$$F = \pm\frac{B_0}{1{,}200} + \frac{B_1}{550} + \frac{B_2}{1{,}380} \quad . \quad . \quad (35)$$

for road bridges, with $n=1.2$,

$$F = \pm\frac{B_0}{1{,}200} + \frac{B_1}{600} + \frac{B_2}{1{,}500} \quad . \quad . \quad (36)$$

In all formulas B_0 has the + or − sign, according as B_0 representing a load in the same sense as or opposite to, max B. Hence for tension only or compression only the + sign must be used.

Winkler recommends that formulas (31)−(33) should be used even when max B denotes compression, provided that, as in the case of tension, under F the nett sectional area (after deducting the rivet-holes) be understood.

If in formula (30) B_1 and B_2 are expressed by (17)−(20) in terms of the limiting loads, there follows with reference to the expressions (1) and (2),

$$b = \frac{\max B}{F} = \frac{(1-a)b_r}{n(1-a\varphi)-(n-1)(1-a)\varphi_0} \quad . \quad (37)$$

For railway bridges in particular there results with $n=1.3$, where max B denotes tension and $b_r = 1{,}400$, $a=0.45$,

$$b = \frac{770}{1.3-0.585\varphi-0.165\varphi_0} \quad . \quad . \quad . \quad . \quad (38)$$

and if max B denote compression, and $b_r = 1{,}200$, $a=0.40$,

$$b = \frac{720}{1.3-0.52\varphi-0.18\varphi_0} \quad . \quad . \quad . \quad . \quad (39)$$

Some objections to the preceding formulas cannot be overlooked.

For alternate tensile and compressive loads of equal magnitude, that is for $\varphi = -1$, either the tensile or compressive load may be regarded as max B, and then both formulas (32) and (35), or (38) and (39), should yield equal values. Instead of this, however, for $\varphi = -1$ and the subjoined values of B_0 and φ_0 the following results are obtained:

B_0	φ_0	by (38)	φ_0	by (39)
Compression..	−1	376	+1	439
" ..	$-\frac{1}{2}$	391	$+\frac{1}{2}$	416
0.....	0	408	0	396
Tension	$+\frac{1}{2}$	427	$-\frac{1}{2}$	377
"	+1	448	−1	360

From this it appears that differences up to 17.5 per cent. of the mean values from both formulæ may occur.

That Winkler should take the admissible stress for compression without liability to buckling as smaller than for tension (1,200 as against 1,400 for b_r) is remarkable, and altogether the expression adopted for a does not appear sufficiently warranted by Wöhler's results. In order to arrive at such expressions, experiments made with the same material, and under the same conditions only should be utilized, because only in this case does the effect of variable loads undisturbed by other influences show itself.

For unhardened Krupp spring steel with $u = 500$ Centner primitive strength, and $t = 1{,}100$ Centner at least per square inch Rhenish, with which the most complete experiments were made, the following are the results obtained by different methods with initial stresses:

	$a' =$	0	250	400	600	1,100
Wöhler's experiments*	$a =$	500	700	800	900	(1,100)
Launhardt's formula	$a =$	500	711	800	900	1,100
Winkler's formula	$a =$	500	612	680	770	995

V.—Formulas of Cain Smith and Seefehlner.

In order to make the well-known empiric formulæ for liability to buckling agree with some older proposals of a committee of the American Society of Civil Engineers, Professor Cain of Charlotte, North Carolina, adopted, as representing the admissible static stress of

* Wöhler, "Die Festigkeitsversuche mit Eisen und Stahl," Berlin, 1870.

iron bars subjected to compression, the expression

$$(a)\quad b_r = \frac{1}{4+\frac{1}{10}\left(\frac{l}{d}-15\right)}\,\frac{t}{1-\delta\left(\frac{l}{r}\right)^2},$$

when l denotes the length of bar $r^2 = \frac{I}{F}$, the square of the least radius of gyration of the section, d the diameter of the bar at right angles to the axis for θ, t the crushing stress, δ a canstant, having for bars held fast at both ends, or supported on flat surfaces, the value 1 : 36000, for bars attached by pins at both ends 1 : 18000, and for bars held fast at one end and attached by a pin at the other 1 : 24000.

In recognizing Wöhler's experiments Cain has regard principally to lattice girders.* He assumes that the effect of impact diminishes with increasing weight of the members of a structure. That the weight of the web members increases tolerably uniformly from the middle towards the ends of the girders, equally so the ratio φ of the limiting loads on the members. Consequently it may be assumed with sufficient accuracy that the effect of impact increases proportionally with φ. Hence if for iron, by Launhardt and Weyrauch's formula $b = c\left(1+\frac{\varphi}{2}\right)$ then the empirical value to be used expressed in kilograms per square centimeter would be

For rods in tension

$$b = 525\,(1+\varphi) \quad . \quad . \quad . \quad . \quad (40)$$

For members in compression

$$b = \frac{1}{4+\frac{1}{10}\frac{l}{d}}\,\frac{2{,}700}{1+\delta\left(\frac{l}{r}\right)^2}(1+\varphi). \quad (41)$$

for alternate tension and compression Cain simply makes $\varphi = 0$.

Mr. Seefehlner, engineer of Budapest, in applying Launhardt and Weyrauch's method, wished to take separately into account the effect of impact.† In the first instance, for the ultimate working strength of iron, he sets

$$(b)\quad a = u\left(1+\frac{\varphi}{2}\right) = \frac{2t}{3}\left(1+\frac{\varphi}{2}\right).$$

"If it is desirable to include in the factor of safety m the influence of the impact of the moving load, it may be considered that the influence of the latter is greater for small bridges than for large spans, Wöhler's experiments also show that as the difference in the limiting stresses decreases the working strength increases, hence may be written

$$m = \mathrm{A} - \mathrm{B}\varphi,"$$

and therefore the admissible stress per unit of area in general for iron

$$b = \frac{a}{m} = \frac{2+\varphi}{\mathrm{A}-\mathrm{B}\varphi}\,\frac{t}{3} \quad . \quad . \quad . \quad (42)$$

here Seefehlner chooses the following values, $t = 3{,}600$, $\mathrm{A} = 4$, $\mathrm{B} = 1.6$, consequently

$$b = \frac{2+\varphi}{4-1.6\,\varphi}\,1{,}200 \quad . \quad . \quad (43)$$

$$\mathrm{F} = \frac{\max \mathrm{B}}{b} = \frac{4-1.6\varphi}{2+\varphi}\,\frac{\max \mathrm{B}}{1{,}200} \quad . \quad (44)$$

The imperfection of the Launhardt and Weyrauch method induced Professor Smith of Birmingham to construct a new formula based upon Wöhler's experiments.* He makes the difference of stress.

$$(c)\quad d = \frac{4(t_d+e)(t_z-e)u_z}{(2t_d+u_z)(2t_z-u_z)} = \frac{4(t_d+e)(t_z-e)u_d}{(2t_d-u_d)(2t_z+u_d)},$$

where t_z, t_d, are the statical breaking strengths, and u_z, u_d, the primitive strengths for tension and compression respectively, these all being numerical values without + or − signs; e, on the other hand, is the arithmetical mean of the limiting stresses per unit of area, where tension is to be taken as positive and compression negative. As for alternations of equal tensile and compressive loads d is equal to twice the vibration strength s, there follows from (c)

$$(d)\quad s = \frac{2\,t_z\,t_d\,u_z}{(2t_d+u_z)\,(2t_z-u_z)} = \frac{2\,t_d\,t_z\,u_d}{(2\,t_d-u_d)(2\,t_z+u_d)},$$

and hence generally

$$(e)\quad d = \frac{(t_d+e)(t_z-e)}{t_d\,t_z}\,2\,s.$$

* Cain in Van Nostrand's Eclectic Engineering Magazine, 1877.

† Seefehlner in Zeitschrift des oestreichischen, Ing. u. Arch. Vereins, 1878.

* Smith in "Engineering," 1880.

If temporarily, as the values u_d, t_d, are not known, it is assumed that $u_d=u_z=u$, $t_d=t_z=t$, there follows:

$$(f) \qquad d=\frac{4u(t^2-e^2)}{4t^2-u^2}=\frac{t^2-e^2}{t^2}\,2s.$$

As to the practical application of these formulas no particulars are given.

With regard to a method of taking into account the effect of impact as desired by Gerber, Seefehlner, Schaffer and Winkler, a difference of opinion may exist on the following grounds: (1) the influence of loads which do not gradually increase is already included in Wöhler's results; (2) the effects of impact are not greatest on those members for which the live load B_v is a maximum, while for those parts which, like the rail bearers, are directly exposed to impact, the admissible stress is in any case taken as smaller than for other portions; (3) the influence of differences of stress on bridges must be less than in the case of Wöhler's experiments, in which all the straining actions followed each other very quickly, and this, even when Wöhler's results are taken into account, may be noticed by dividing the influence of the moving load by n_1; (4) according to Fairbairn, Vicat, Thurston, among others, a continuance of the stress is unfavorable, and this might lead to the practice of introducing the fixed load B_e into the calculation multiplied with the factor n_2 as compared with the live load Bv; (5) by a separate treatment of the fixed and live load, not only the determination of dimensions but also the static calculation becomes more complicated, because then B_c and the two limiting values B_v have to be reckoned separately, while otherwise only the limiting loads are used. Let it be now assumed that the influence of impact alone makes it desirable to multiply B_v by n, then by (3) and (4) there would have to be taken into calculation the quantity

$$(g) \quad B=n_2B_e+\frac{n}{n_1}B_v=\frac{n}{n_1}\left(\frac{n_1n_2}{n}B_e+B_v\right).$$

By introducing simply B_e and B_v into the calculation, and taking account of the effects of impact by a general factor of safety, there results $\frac{n_1n_2}{n}=1$, which, in the absence of further data, appears to be generally most suitable.

If, however, the influence of impact is to be accounted for in the way assumed by Gerber, Schaffer, and Winkler, namely, by introducing the limiting forces B_v B_v' resulting from the moving load, into the calculation multiplied with the factor n (tension positive, compression negative), this can in every case be done. As hypothetical limiting loads the expressions

$$(h) \qquad B=B_e+nB_v.$$

$$(i) \qquad B=B_e+nB'_v.$$

are taken, the ratio of the numerically smaller to the numerically greater of these values is denoted by φ, and then (even when liability to buckling is considered) the method of proceeding is exactly as though B and B were the actual limiting loads.* Of course, as the influence of impact is already accounted for, a more favorable factor of safety may be chosen.

Krohn's† method deviates somewhat from this, as from the commencement he reckons with 1.5 time the moving load, but then allows the value

$$(k) \qquad b=1{,}000\left(1+\frac{\varphi}{2}\right).$$

In the present state of knowledge on the subject, and with regard to the matter generally, excessive refinements appear to the author unsuitable.

VI.—Ritter's Hypothesis.

In a paper of the year 1877‡ Mr. Fr. Ritter, an engineer of Vienna, aims at placing the facts relative to the strength of materials proved by Wöhler's experiments upon a deeper foundation.

According to Ritter, the assumption is a plausible one, that the destructiveness of repeated stresses is inversely proportional to their distance from the statical breaking strength t. The resulting destructiveness of every stress varying between the limits a and $\pm a'$ may not exceed a certain value for a given material. "This value is independent of the relative position of the vibration as regards o and t, so that when the position changes, and, according to the preceding,

* For further information, *vide* Crugnola-Weyrauch, "Stabilita delle construzioni in ferro et in acciao," Turin.

† Krohn, "Resultate aus der Theorie des Brückenbaues," Aachen, 1879.

‡ Fr. Ritter, "Die Festigkeitsverhaltnisse nach den Wöhlerschen Versuchen."

each individual oscillation becomes more or less destructive, not the sum of the individual destructiveness is altered, but on the other hand the admissible limits of the resulting vibration become narrower or wider." Ritter claims to express this hypothesis by the formula

$$(a) \qquad \int_{\pm a'}^{a} \frac{t}{t-a}\,da = \text{const},$$

whence when k is a constant for tension or compression only

$$(b) \qquad \frac{t-a'}{t-a} = k,$$

and for alternate tension and compression on account of the expression

$$\int_{-a_1}^{a} = \int_{o}^{a} + \int_{o}^{a'}$$

$$(c) \qquad \frac{t}{t-a} \cdot \frac{t}{t-a'} = k.$$

For a factor of safety m, the admissible stress per unit of area $b=\frac{a}{m}$ and $a=mb$. As by (1) for a piece subjected always to tension or always to compression $a'=\varphi a$, there follows from (b)

$$(d) \qquad \frac{t-m\varphi b}{t-mb} = k$$

$$b=\frac{k-1}{k-\varphi}\frac{t}{m} \quad . \quad . \quad . \quad (45)$$

As further, with alternate tension and compression, by (2), $a'=-\varphi a$ there results from (e)

$$(e) \qquad \frac{t}{t-mb}\,\frac{t}{t+m\varphi b} = k$$

$$b=\left\{-\frac{1-\varphi}{2\varphi}-\sqrt{\left(\frac{1-\varphi}{2\varphi}\right)^2+\frac{k-1}{k\varphi}}\right\}\frac{t}{m} \quad (46)$$

For iron in particular Ritter makes $k=2$, $m=3$, $t=3{,}600$, whence for tension only or compression only

$$b=\frac{1{,}200}{2-\varphi} \quad . \quad . \quad . \quad (47)$$

$$F=\frac{\max B}{b}=\frac{2-\varphi}{1{,}200}\max B \quad . \quad (48)$$

and for alternate tension and compression

$$b=\frac{\varphi-1+\sqrt{1+\varphi^2}}{\varphi}600 \quad . \quad . \quad (49)$$

$$F=\frac{\varphi}{\varphi-1+\sqrt{1+\varphi^2}} \cdot \frac{\max B}{600} \quad . \quad (50)$$

For $\varphi = 0$ the last equation gives $\frac{0}{0}$, then however (43) is applicable and gives $b=600$.

ON THE MEASUREMENT OF ELECTRICITY FOR COMMERCIAL PURPOSES.*

By JAMES N. SHOOLBRED, B. A., Mem. Inst. C. E.

From "The Engineer."

THE present remarks are intended to deal more especially with the commercial question, raised by what is termed the "supply of electricity," in the Electric Lighting Act, 1882, the objects of such supply being more particularly lighting for public and private purposes, and the transmission of power. All these require electric currents of such magnitude as are generally produced by dynamo machines. To such branches of the subject as telegraphy and telephony, excepting in the general principles common to electric currents, the scope of the paper, and especially the special form of the various apparatus described, will but indirectly apply. The remarks must, in fact, be taken as mainly referring to an electric supply by mechanically-generated induction currents. The basis and principle upon which rests this mode of producing electricity is the conversion of mechanical into electrical energy. Any exact financial evaluation of the commodity produced and offered for sale, involves a knowledge, by measurement, of the amount of this energy, not merely of the electrical energy as offered to the customer, but also of the mechanical which is expended and absorbed in such offer.

* Read before the Society of Telegraph Engineers and Electricians.

The former is a question mainly for the consumer, the latter for the producer, who must, however, check the two together to enable him to arrive at the fair marketable value of the supply which is offered for sale. In most cases the evaluation of the mechanical energy expended resolves itself into coal, wages, engine-room expenses, outside working and collection charges, interest on capital expended, and depreciation on plant employed, but chiefly on the two first-named items—coal and wages. It is not intended in these remarks to deal with this portion of the subject, which is one of statistics, but with the more pertinent one, to this society at least, of how to measure and value the electrical product resulting from the above expenditure. Before dismissing the former, the mechanical branch of the subject, it may be well to advert to the similarity, in most cases, and taken broadly, in the nature of the conditions of manufacture and of supply of electricity and of gas, both for illumination and for power. Each starts with coal, the energy of which it transforms into a commodity for the purposes just named; and it is in the process of transformation, in the nature and costliness of the intermediate operations, and in the amount and value of the plant and working expenses involved in each system respectively, that the main commercial difference between the two must exist. Iron forms a large part of the material of the plant necessary in both, and coal and wages, subject to the same conditions and variations, form the main bulk of the working expenses of the two systems. This similarity in objects and in operations is here referred to, in order to point out that, as it is by the careful experience of more than half a century, the conditions, both legal and social, have been ascertained for the supply of gas—and also, it should be added of water—it need not, therefore, be surprising if some of these conditions, stamped with the seal of every-day practice, should be found to adapt themselves, or to be worth while taking into consideration, in the case of electricity, the differences in the processes of production, and of the products themselves, being always remembered. The valuation of the electrical energy of the supply depends upon the exact measurement of two factors—the amount of the supply and the pressure under which it is given, or, in other words. the quantity of the current, and the difference of potential—or electromotive—force which the consumer is able to avail himself of. As there appears to exist a misconception, in some quarters, as to the exact terms in which the various electrical units have been defined, and the precise duty of each, more especially as to the "ampère" and the "coulomb"—for each of which the term "weber" was formerly and almost indiscriminately used—it may be well to give the sense of the resolutions passed at the International Congress of Electricians, held in Paris in 1881, and now universally accepted.

Electrical units.—The fundamental units adopted are those of the centimeter—length—the gramme—mass—and the second—time—or, as it is called for brevity, the C.G.S. system. For practical units the following are adopted: The ohm—10^9 C.G.S. units—as the unit of resistance, is that of a column of mercury having one square millimeter of section, and of a length hereafter to be determined by a commission specially appointed for the purpose. *Note.*—The length is supposed, however, to be between 104 and 105 centimeters. The volt—10^8 C.G.S. units of electro-motive force—as the unit of electro-motive force. *Note.*—This corresponds nearly to that of a Daniell's cell. The ampère—10^{-1} C.G.S. units of current—as the unit of current, which is the current produced by one volt through one ohm. The coulomb—10^{-1} C.G.S. units of quantity—as the unit of quantity of electricity, which is defined by the condition that an ampère yields one coulomb per second. The farad—10^{-9} C.G.S. units of capacity—as the unit of capacity, which is such that one volt in a farad shall give one coulomb. Or, to quote the words of Sir Wm. Thomson—the chairman of the British Association Committee which settled the C.G.S. system of units above referred to—when explaining the practical units to the Congress: "The volt acting through an ohm gives a current of one ampère, that is to say, one coulomb per second; and the farad is the capacity of a condenser, which holds one coulomb, when the difference of potential of its two plates is one volt." The

following were also suggested by Dr. C. W. Siemens, at the British Association Meeting, 1882, to be added to the above units: The watt—10^7 C.G.S. units of power—as the unit of power; being the power conveyed by the current of one ampere in one second through a conductor whose ends differ in potential by one volt. The joule—10^7 C.G.S. units of work—as the unit of work, or heat, being the heat generated by a watt in a second. Although the unit of quantity, as defined, is the coulomb, yet it is sometimes found more convenient to express measurements of quantity in terms of the current or rate of flow in amperes. Thus it is more convenient, sometimes, to say "one ampere hour" than "3,600 coulombs," as the result of work done by a current of one ampere flowing continually, and uniformly, for the space of one hour. The product of the current expended, in ampere seconds, or of this amount of quantity expended in coulombs, by the electrical pressure of the same, expressed in volts, gives the electrical energy expended, or power of the supply expended in watts. The electrical energy is, therefore, represented by the product of volts × amperes × time; or, by the product of volts × coulombs, or, expressed algebraically, $W = E\ C\ t = E\ Q$. The following are the equivalent expressions for the same amount of energy, only expressed in other terms, some of which may, perhaps, be more familiar:

Energy expended per second.

Volt × ampere =
- 1 watt.
- $1 \cdot \frac{1}{746}$ foot-pounds.
- $9 \cdot \frac{1}{81}$ kilogrammeters.
- $\frac{1}{736}$ force cheval — French horse-power.
- $\frac{1}{746}$ horse-power indicated.

It is suggested in some of the—draft—provisional orders for the supply of electricity, now before the Board of Trade, that the unit of price to be charged should be based "on the energy contained in a current of 1,000 amperes, flowing under an electro-motive force of one volt during one hour;" or, in other words, the unit might be put as 1,000 volt-ampere-hours. Since the ampere hour is another way of saying 3,600 coulombs of quantity of electricity supplied, this above expression may be put thus, as representing the value of the above unit.

Work done.

1000 volt-ampere-hours =
- 3,600,000 volt-coulombs.
- 1000 watt's hours.
- 1.34 horse-power hours.
- 2,653,200 foot-pounds.
- 1.36 force cheval heures—French horse-power hours nearly.
- 100 kilogrammeters.

Put in terms more in accordance with actual practice, the above unit might mean the supply for one hour of a current of ten amperes with an electro-motive force of 100 volts. To arrive at a due evaluation of the supply of electric energy, it is evident that the measurement of each of these two factors—in volts and amperes respectively—should be effected either separately or combined; and also that a continuous and cumulative record should be kept of the supply as it proceeds. Many instruments exist for the measurement of the above elements at any particular time, but without any means of continuously recording such measurements. These evidently, except under certain conditions, cannot comply with the commercial conditions required for ascertaining the amount of supply. It is only, therefore, instruments furnished with means of continuously integrating, or recording the successive progressions of the supply, or instruments to which such recording apparatus can readily be attached, that come properly within the scope of this paper. To measure with completeness for commercial purposes a supply of electricity will entail, therefore, a continuous record of each of the two elements just referred to, current and pressure, either separately or combined. In the supply of towns, however, the question for the consumer, may, and will most probably, be much simplified by causing one of these elements, that of pressure, to remain constant, since it is very likely that a constant standard pressure of supply will be fixed by the Government in granting the several provisional orders. If so, it then becomes the duty of the suppliers to keep up to that pressure under penalty; and instruments for recording such pressure will have to be installed where required, and placed under proper supervision. For the customer, however,

it will then generally suffice to have an exact record of the quantity only of his individual consumption of electric supply. It has been thought advisable to precede the description of the recording or registering instruments, which alone are meters in the commonly-accepted sense of the word, by an enumeration of some of those non-recording instruments which are in more general use, since they suffice for present exigencies. This short descriptive enumeration is even almost necessary, since most of these instruments, by the addition of some recording apparatus or appliance by which the element of time can be integrated, may be made to enter into the class of registering meters. Indeed, some of them already possess their representative in this second class, or else have given rise to some modification, which has complied with the requirements in the latter case. Thus, any current or ampère measurer may be converted into a record of quantity, or a coulomb meter, by the integration of the time during which the current has flowed; and similarly, any power or volt-ampere measurer may become a register of work done by means of the addition of the elements of time. Again, volt or pressure measurers, will always be required in any case where a check is required upon the actual difference of potentials, or electro-motive force of the supply, and this may arise from a variety of causes.

Non-registering instruments.—Current meters: Siemens' electro dynamometer;* Professors Ayrton and Perry, ammeter;* Sir Wm. Thomson, current galvanometer; Capt. Cardew, R.E., low resistance galvanometer;* Dr. Obach, tangent galvanometer;* Marcel Deprez, galvanometer. Pressure meters: Professors Ayrton and Perry, volt-meter; Sir Wm. Thomson, potential galvanometer; Siemens' torsion galvanometer; Marcel Deprez, galvanometer. Power, or energy, meters: Professors Ayrton and Perry, power meter; C. V. Boys, power meter.

Registering meters.—Quantity, or coulomb, meters: (1) Electrolytic: T. A. Edison, total deposition; T. A. Edison, alternations of deposition; J. T. Spague, alternations of deposition. (2) Mechanical: Dr. J. Hopkinson, rotating meter; C. V. Boys, vibrating meter; Theos. Varley and Greenwood, disc meter; Professors Ayrton and Perry, fluid friction on magneto-electro motor;* T. A. Edison, fluid friction on magneto-electric motor.† Energy, or work, meters: Professors Ayrton and Perry, ergmeter; C. V. Boys, energy meter; Deprez-Abdank, energy meter.

Edison's current meters.—These are based upon electro-deposition of metal, due to the action of a known fractional part of the total current. The weight of the increments is ascertained periodically, and from it the total quantity of the current which has passed during the interval is deduced. The metal now generally used consists of plates of zinc, immersed in a solution of ninety parts of sulphate of zinc and one hundred parts of pure water. In the form of meter for commercial use, two cells are placed as a check against one another; one, termed the "monthly cell," receiving four times the current of the other, which is known as the "quarterly cell." In order to prevent the temperature of the liquid in the cells falling so low as to freeze, a connection is made by means of a long thin strip of brass and steel rivetted together to an incandescent lamp, which is thereby lighted and raises the temperature as required. It is only when the temperature falls to 42° Fah. that this tongue is sufficiently depressed to form contact, and so to light the lamp. On the temperature rising the tongue rises, and the lamp is extinguished. Experience shows that electro-deposition, to give a true and reliable record, should not be forced or overworked in its action; and that the plates should not in their daily duty be required to do more work, or be longer in action than they are intended for by their superficial area. In practice, about 75 per cent. only of their nominal work should be required of them. Several other forms of meter have been devised by Edison, such as his beam meter, where, when the increments by electro-deposition have accumulated to a certain limit, the current is reversed and the accumulation is re-dissolved, to re-commence again when the normal condition is gained; and, again, electric-motor meters, by fluid pressure, etc. All of these

* See "Journal" Soc. Tel. Engrs.—No. 43, vol. xi. Sept. 1882.
† See "Journal" Soc. Tel. Engrs., Sept. 1882.

have, it is said, in practice been found—in cases where the total current supplied is very small, and this often so—to require so large a proportion of it for these mechanical operations, as to make the record unreliable. The meter first described, by electrolytic action only, is therefore now generally adopted by Edison.

Sprague's meters.—These instruments are based upon electro-deposit up to a certain point; *i. e.*, when the intended quantity of metal, whether copper or zinc, has been deposited on the plate. The current is then reversed, and the metal gradually dissolved again until the primary condition of the plate is reached; when, by another reversal of the current, deposition again commences; each reversal of the current being recorded by a mechanical counter and a train and wheels. Not much practical experience has so far been obtained with these meters; but, what has been done, tends to point out that the mechanical operations involved in the reversals of the current, and in their registration, absorb a large amount of power.

Hopkinson's current meter.—This instrument consists of a thick wire coil, in the form of a solenoid, through which the current passes to be measured. The iron core of this solenoid revolves with its central shaft by the action of the armature of a small dynamo machine, placed at one end of the shaft. The core of the solenoid is in two parts; the lower is fixed to the shaft, while the upper is movable, being attached to a governor ball arrangement, and sliding up and down the shaft in accordance with the variations in the rotation speed of the shaft. A shunt current passes through the dynamo and its armature, then up through the lower or fixed portion of the core, and—by contact only—to the sliding part, and thence to the framework of the apparatus. If the movable core be lifted, owing to the speed of rotation by the action of the governor balls, this circuit is broken, and the shunt current through the dynamo interrupted. Whenever a current to be measured passes through the coil, attraction, by means of its casing, takes place between the fixed and the movable parts of the iron core. This magnetic action, which is proportional to the square of the current, tends to keep the two parts of the core together and in contact, while the centrifugal force of the governor balls, which is proportional to the square of the speed of revolution, tends to break the contact by lifting the movable part. These opposite forces will, in working, balance one another, and the result is that the system revolves with a velocity proportional to the current through the coil. As the revolutions of the shaft are transmitted continuously by a train of wheels to a set of index dials, a record is thus kept of the quantity of the current that has passed. In the construction of the apparatus the weight of the core is taken off by springs. The arrangement of the parts, as now made, is shown on the diagram.

Boys' quantity or vibrating meter.—This instrument is based upon two well-known principles. (1) The force acting on the armature of an electro-magnet, in any position, is proportional to the square of the current. (2) The square of the number of vibrations, say, of a pendulum, is a measure of the controlling force. Therefore, if the controlling force under which a body vibrates is due to the action of an electro-magnet on its armature, the square of the number of vibrations in a given time is a measure of the square of the electric current. In other words, the rate of vibrating is a measure of the strength of the cuarent, and the number of vibrations is a measure of its quantity. The exact form and nature of the meter may vary in many details. The one now shown consists, primarily, of an electro-magnet—the upper one in the diagram—through the coils of which passes a portion of the main current to be measured. This magnet is placed horizontally, and a vertical rocking shaft stands between its poles. This shaft has fixed on it a soft iron armature, rounded at the ends, and free to move in the horizontal plane between the poles of the electro-magnet. The intensity of the attraction between the poles and this armature determines the rate of vibration; which, as above-stated, is a measure of the strength of the current. Each vibration is itself recorded by means of an escapement, a train of wheels, and a set of index dials; and the number of vibrations thus registered becomes a measure of the quantity of the current. To add to the momen-

tum of the vibrating body, two long arms, weighted at the end, are attached to the lower part of the vertical shaft. In order, likewise, to prevent the vibrating armature from gradually coming to rest, it is arranged that, when the vibrations fall below a certain limit, by making contact, a portion of the current is sent round the coils of a second or "impulse" electro-magnet—placed underneath the "controlling" magnet—and which has an armature of a suitable form fixed on to the same shaft that carries the armature of the upper magnet. The extra motion thus given to the shaft, by the attraction of the lower armature, affords the necessary impulse to the vibrating armature when required to do so.

Boys' energy meter.—This instrument consists of two parts: (1) the indicator of energy, and (2) the integrating apparatus. (1) In the indicator of energy, a balanced beam has from one end suspended a counterweight, and from the other a hollow solenoid, free to work up and down into two other fixed solenoids. The movable solenoid is wound with a considerable length of fine wire; in the upper half in one direction, in the lower in the opposite—this is to render it independent of any magnet which may be placed near to it. This solenoid constitutes the high resistance shunt which measures the electro-motive force. The two fixed solenoids are wound with thick wire, and convey the main current. The result of the action of the fixed and the movable solenoids on each other is a force proportional to the product of the two currents, that is the energy being expended, but the external evidence of this is the inclination of the beam, and this inclination, or rather the tangent of the inclination, is proportional to the energy being expended. (2) The recording apparatus consists of a cylinder, which by means of a mangle motion is made to reciprocate backwards and forwards by clockwork, and during its passage in each direction the cylinder is made to bear alternately against one of two tangent wheels, each free to be inclined in its direction of travel; both are fixed on the same swivelling frame, but only one of them bears at the same time against the cylinder. This frame is free to be inclined from the vertical in correspondence with the inclinations of the beam above mentioned; but the tangent of the inclination of the beam, as has been said, is proportional to the energy of the current; so also, therefore, is the tangent of the inclination of the wheels $\left(i.e., \frac{d\,y}{d\,x}\right)$. The effect of this inclination of the tangent wheel is to cause the reciprocating cylinder to rotate, the speed of such rotation being proportional to the tangent of the inclination of the wheel, which is likewise proportional to the tangent of the inclination of the beam; that is, to the amount of energy expended. The path of the tangent wheel on the reciprocating cylinder, when not inclined, is simply a straight line lengthways along the cylinder, and no rotation is caused, but when, owing to the inclination of the wheel, the cylinder rotates, the wheel pathos becomes a spiral. The rotations of the cylinder are transmitted to a train of wheels and registered, thus giving a record of the amount of energy expended during a given time.

Ayrton and Perry's erg-meter.—This instrument is but a further development or sequel to their power meter, by the addition of apparatus which integrate and record continuously the time during which the electrical energy has been imparted, as well as the variations in its amount. By this means is preserved a record of the entire work done, or of the total electrical energy supplied. As in the power meter, two coils are here made use of, a thick wire one on the main circuit, to measure the amount of current, and a thin wire one on a shunt joining the ends of the main circuit, to measure the difference of potentials or electro-motive force of the main circuit. In the arrangement, as now shown, the thin wire coil, of say one 1,000 ohms resistance, simply replaces the pendulum bob of a clock. The wires from each end of the coils pass up the sides of the pendulum rod and on to the binding screws A and B, which can be joined to the supply and return cables of a house, or machine, or a system receiving electrical energy. In the immediate vicinity of the fine wire coil, fixed to the clock case, and parallel with the plane of the pendulum path, is fixed the thick wire coil, which forms part of the main circuit, and has a very

small resistance. The effect upon the thin wire coil of its repeated passages in front of the thick wire coil is to cause a certain pull or attraction upon its motion—either of acceleration or of retardation, according to the direction of the coiling. This acting, in addition to the ordinary action of gravity upon the pendulum, will keep constantly adding to, or retarding, its rate of motion in proportion to the electrical power of the circuit. This pull is the product of the magnetic moments of the two coils, and therefore is proportional to the product of the current and the electro-motive force. The effects of these repeated accelerations or retardations upon the progress of the clock keep constantly accumulating, and their total amount can at any time be detected and ascertained by observing the amount of loss or gain which the clock has experienced. As the rate of loss or gain in the clock due to different amounts of electrical power has been previously ascertained, this knowledge of the total retardation or acceleration upon the clock is, in fact, a record of the total amount of electricity energy which has been expended, or of the work done, since the last observation of the clock. The principle upon which the erg-meter is based is as follows: Let B C be the thick wire coil, and A B be the thin wire coil. If c be the current passing into the house and the difference of potential of supply and return cable, then $c\,v$ is proportional to the electric horse-power given to the house. Now the time of vibration of the pendulum is $t=\pi\sqrt{\frac{M}{g-kcv}}$. If the magnetic force is a retarding one M, g, v π are constants—that is, if the time of clock, when no electricity is passing, be called T, hen $\frac{T}{t}=\sqrt{\frac{g-kcv}{g}}$. Now, care is taken that the magnetic forces are very small in comparison with gravitation forces acting on the pendulum bob; so that, to a degree of approximation which is sufficiently correct in practice, the above equation becomes $\frac{T}{t}=1-\frac{k}{2g}cv$. The rate of loss in the clock is therefore represented by $\frac{k}{2g}cv$. That is, it is proportional to $c\,v$, the electrical power. Hence, the total loss of the clock during any time represents the total electrical energy given to the house during that time. For the reasons stated in the earlier part of the paper, it is probable that the supply of electricity in a town will be carried out at a certain defined standard pressure of electro-motive force, which will be guaranteed to the consumer; and to assure the fulfillment of this condition, special steps will be taken by the local or other authority. The consumer need therefore but concern himself, as far as the supply he receives and has to pay for, with the quantity of electricity which he has made use of. In fact, the meter he makes use of to record it may be a coulomb meter. The work or energy meters will not be needed for general application, but only in special cases, where the complete record of the total electrical energy supplied is required. In what form, therefore, will it be most convenient for these coulomb meters to present their record? or, in other words, upon what unit should that register be based for commercial calculation? With the sole exception of those meters based upon electrolytic action, and which simply present the total of the increments of the metal, which are proportionate to the total quantity of current which is passed, the record presented is the result of a series of mechanical actions indicative of the strength and duration of the electrical supply. It is seen how these successive mechanical operations may be recorded in a cumulative way by the ordinary arrangement of a train of wheels; both in the case of those meters based upon electrolytic action, and causing periodical reversals in the direction of the current, and also in those where the action due to the current is a purely mechanical one. There remains then but the question of the mode of graduation of the respective indicating dials. The unit already referred to, as being proposed to the Board of Trade in several provisional orders as "the energy in a current of 1000 ampères with an electromotive force of one volt flowing during one hour," has been shown to mean 1000 volt-ampere-hours, or 3,600,000 volt-coulombs. As it is probable that one of these factors—the volt—being fixed and constant, may be taken out of the commercial calculation for the consumer, it

is worth while considering what dimensions the remaining factor—the coulomb—would assume under the ordinary conditions of practice; and hence what would be most convenient graduation of the dials to embrace these dimensions; but the commercial question requires also a financial expression in which to reckon these dimensions. The money value accompanying the suggestion of the above 1000 volt-ampere-hours unit, and which is sought to be attached primarily to 100 of these units is in some provisional orders 70s., in others 75s. Though it would be quite out of place in this paper to attempt to assign any financial value for the supply of electricity, yet for the nonce, and in carrying out the analysis of the above unit, as it might work under the conditions of actual practice, it is necessary to assume a money value. In the annexed table, which takes into consideration the effect of different rates of electro-motive force, according as they may be fixed, 70s. is assumed as the money for 100 units of 1000 volt-ampere-hours each.

Comparative Values of Supply of Electricity per 100 *units* (*of* 1000 *V.-A.-hours*) = £3 10*s.*

(1000 volt-ampere-hours=3,600,000 volt-coulombs.)

E.M.F. Volts.	Price.			
	100 Coulombs	10,000 Coulombs	100,000 Coulombs	1,000,000 Coulombs
	Pence.	Pence.	s. d.	£ s. d.
100	.23	2.33	1 11.3	0 10 5
110	.26	2-57	2 1.7	1 1 5
120	.28	2.8	2 4	1 3 4
130	.3	3.03	2 6.3	1 5 3
140	.32	3.27	2 8.7	1 7 3
150	.35	3.5	2 11	1 9 2
160	.37	3.73	3 1.3	1 11 1
170	.4	3.97	3 0.7	1 13 1
180	.42	4.2	3 6	1 15 0
190	.44	4.43	3 8.3	1 16 11
200	.46	4.67	3 10.7	1 18 11

The prices in this table are based on the assumption that the price per coulomb unit remains at the same rate, irrespective of the intensity of the electro-motive force. As a matter of fact, the amount of the latter ought certainly to be taken into account in fixing the sale price. Thus, with a pressure at 200 volts, the price for a certain number of coulombs ought not to exceed two-thirds of that of the same supply at 100 volts of pressure, in consequence of the economy in the former case, in the distributing mains, and in general working expenses. From a careful consideration of this table, it would appear that the amount of 100,000 coulombs would form a convenient unit of value whereby to reckon the commercial price. It would also serve as a basis of graduation for the indicating dials of the meters, with subdivision to $\frac{1}{10}$ and $\frac{1}{100}$ parts. The annexed diagram shows an arrangement of indicating dials, graduated in the first case with the unit suggested in the provisional orders, 1,000 ampere hours; in the second the unit is 100,000 coulombs as just suggested. The electro-motive force in each is taken at 100 volts. The proportion between the two systems of graduating in the present instance is as 3.6 to 10—3,600 being the number of coulombs which is the result of the flow of a current of one ampere for one hour; $\frac{3{,}600{,}000 \text{ coulombs}}{100 \text{ volts}}$ is, therefore, the actual quantity value of the first unit—1,000 ampere hours; as against 100,000 coulombs, the quantity contained in the second unit.

The values in C. G. S. units are { Volt-ampere-hour unit = 10^{7}. Coulomb unit 10^{1}.

The advantage of the coulomb unit is that it expresses an actual quantity, whereas the ampere hour unit is but a time-rate, which as a matter of fact, has to be translated into its corresponding quantity. The coulomb method of graduation could be applied uniformly to all quantity meters, whereon they might happen to be afterwards used, inasmuch as the special rate of electro-motive force, or standard pressure, in each particular locality would be taken into account in the price there charged for the electric supply. This uniformity in manufacture would further reduce the expense of this, already the simpler form of registering meter. With the volt-ampere method, to use a quantity meter—as shown in the index-dial diagram—requires the exact position of the unit to be set according to the particular electro-motive force

with which it is used, inasmuch as the quantity record is only one factor in the unit. This limited use of each particular recording meter would tend to create error and confusion. An energy meter alone would supply a complete record of the volt-ampere-hour mode of measurement; and this is a form of meter which involves a clock or some other time record, and consequently is a more expensive apparatus, and one requiring an amount of attention from the consumer which it would be impossible, in many cases, to expect. Thus, though the volt-ampere system may present, theoretically, a complete and convenient means of recording the supply of electricity, yet, in actual practice, the coulomb system would meet all wants, and be more suited to general application.

ON THE EFFECT OF THE EARTH'S ROTATION ON BODIES MOVING ON ITS SURFACE.

By PROF. J. E. HENDRICKS.

That any meridian plane of a revolving sphere will rotate, with respect to a fixed plane, around a normal axis, which pierces the sphere at any point of its surface, with a uniform angular velocity equal to the angular velocity of the revolving sphere multiplied by the sine of the latitude of the point at which the normal axis pierces the surface of the sphere, is a geometrical truth which is wholly independent of any consideration of force whatever. (For a demonstration of this proposition see *American Journal of Science for* 1852, Vol. XIII, p. 212.)

As a consequence of the inertia of matter, a mass in motion, constrained to move about a center, by a constant force directed to that center, will develop a centrifugal force which will be directly proportional to the square of the velocity and inversely proportional to the radius of the circle.

If we pnt R for the earth's equatorial radius and V for its equatorial velocity per hour (sidereal time), we have for its equatorial centrifugal force

$$\frac{V^2}{R}=\frac{g}{289};\ V=\frac{2\pi R}{24} \quad . \quad . \quad . \quad (1)$$

If a velocity v be impressed upon a body, at any point P in latitude λ of the earth's surface, the body will, under the impulse of the impressed force and the earth's gravitating force, move in a fixed plane passing through the center of the earth and therefore intersecting its surface in a great circle of which the point P will be the extremity of a diameter.

Now, in accordance with the above proposition, a meridian plane will, in consequence of the earth's rotation, revolve, with respect to the fixed plane through P, about a normal axis at P, with a uniform angular velocity.

Hence, instead of supposing the moving body to remain in the fixed plane, if we suppose it to be deflected from its path by the rotation of a meridian plane around the normal at P, it will be, at every point of its path, forced to move with a uniform velocity at right angles to a tangent at that point, and hence will be compelled to describe a circle, and will by the above proposition, return to P in the time occupied by the meridian plane in making one rotation about the normal at P, viz., 24 hours divided by $\sin\lambda$; therefore the circumference of the circle in which the body is forced to move is $24v\div\sin\lambda$, and its radius is $24v\div 2\pi\sin\lambda$, and because the deflecting or centripetal force f acting on the body is to the earth's equatorial centrifugal force directly as the squares of their velocities and inversely as their radii;

$$\therefore f : \tfrac{1}{289}g :: \frac{v^2}{24v\div 2\pi\sin\lambda} : \frac{V^2}{R};$$

$$\text{or } f : \tfrac{1}{289}g :: \frac{2\pi v\sin\lambda}{24} : \frac{4\pi^2R}{(24)^2};\ \text{whence}$$

$$f=\frac{\frac{1}{289}g24v\sin\lambda}{2\pi R}. \quad . \quad . \quad . \quad (2)$$

Equation (2) represents the total deflecting force at P which results from the rotation of the tangent plane around the normal, and is entirely independent of the direction in which the body moves, provided the centrifugal force of the moving body corresponds with that of

the earth's surface at the point P; but this is only the case when the initial motion of the body is in the meridian of P.

Let β denote the angle between the meridian plane and the initial direction in which the body moves, estimated from the south toward the west, then is the centrifugal force of the earth's surface at P to the centrifugal force in the same orbit due to the velocity v as $V^2 \cos^2 \lambda$ is to $v^2 \sin^2 \beta$ or

$$\tfrac{1}{2}\tfrac{1}{8}\tfrac{1}{9}g \cos \lambda : F :: V^2 \cos^2\lambda : v^2 \sin^2\beta,$$

from which we find

$$F = \frac{\tfrac{1}{2}\tfrac{1}{8}\tfrac{1}{9}g v^2 \sin^2\beta \cos\lambda}{V^2 \cos^2\lambda} = \frac{\tfrac{1}{2}\tfrac{1}{8}\tfrac{1}{9}g v^2 \sin^2\beta}{V^2 \cos\lambda}.$$

Resolving F into horizontal and vertical components at P, we find for its horizontal component

$$F' = \frac{\tfrac{1}{2}\tfrac{1}{8}\tfrac{1}{9}g(24)^2 v^2 \sin\lambda \sin^2\beta}{4\pi R^2 \cos\lambda} = \frac{24v \sin^2\beta}{2\pi R \cos\lambda} \times \frac{\tfrac{1}{2}\tfrac{1}{8}\tfrac{1}{9}g 24v \sin\lambda}{2\pi R} \quad . \quad . \quad . \quad (3)$$

Adding equations (2) and (3) we get for the total deflecting force at P

$$f + F' = \left(1 + \frac{24v \sin^2\beta}{2\pi R \cos\lambda}\right) \times \frac{\tfrac{1}{2}\tfrac{1}{8}\tfrac{1}{9}g 24v \sin\lambda}{2\pi R} \quad . (4)$$

If we suppose the point P to be in latitude 87° 45′ and v to represent a westward velocity of 40 miles per hour, the body though moving at the rate of 40 miles per hour relative to the earth's surface, will be in a state of absolute rest, and will therefore develop no centrifugal force about the earth's axis, and consequently it will tend to a state of equilibrium by moving toward the pole, or to the right, with a force represented by the earth's centrifugal force at that latitude resolved in the direction of the tangent plane, *i. e.*, with a force $= \tfrac{1}{2}\tfrac{1}{8}\tfrac{1}{9}g$ $\cos\lambda \sin\lambda$; this result is obtained independently of any consideration of the rotation of the meridian about a normal axis at P, and from which there results precisely the same deflecting force at that point, as shown by equation (2). Hence equation (4) is true when $v = V\cos\lambda$, and is therefore true for all values of v and β.

If the moving body be a pendulum suspended at P in latitnde λ, its centrifugal force about the earth's axis will correspond with that of the point P, and v in equation (3) will become zero, so that in whatever direction a pendulum may be vibrated, its deflecting force will be completely represented by f in equation (2); for the centrifugal force produced by the motion of the pendulum about its point of suspension is always in the plane of that motion and therefore has no tendency to deflect the pendulum out of that plane; but the velocity v' with which the pendulum passes the point P, if referred to the earth's axis as its center of motion, may be substituted for v in equation (2) and hence f in equation (2) represents the whole of the deflecting force, or reaction, which a pendulum vibrating with a maximum velocity v' would exert on the rotating meridian through P.

As the term F′, equation (3), results from the difference between the centrifugal force of the moving body and that of the point P, about the earth's axis, if the moving body be a projectile this term will vanish, but in its stead we shall then have the term

$$F'' = \frac{v \cos\lambda \cos\beta}{\sin\lambda} \times \frac{\tfrac{1}{2}\tfrac{1}{8}\tfrac{1}{9}g 24 v \sin\lambda}{2\pi R}, \quad . (5)$$

so that, at the end of any time t, the deflecting force will be

$$f + F'' = \left(1 + \frac{v\cos\lambda\cos\beta}{\sin\lambda}\right) \times \frac{\tfrac{1}{2}\tfrac{1}{8}\tfrac{1}{9}g 24v\sin\lambda}{2\pi R} \quad (6)$$

Because the second term in the parentheses in equation (4) vanishes when $\sin\beta = 0$ and the corresponding term in equation (6) vanishes when $\cos\beta = 0$, it follows that, for a projectile, the deflecting force is a maximum when the direction of the motion is in the plane of the meridian, while for a body moving on the earth's surface, as a locomotive on a straight track, the deflecting force is a maximum when the track is at right angles with the meridian through the origin of the motion.

In a paper on this subject published in *Van Nostrand's Engineering Magazine* for June, 1883, p. 468, Mr. Randolph says truly that, "While the earth was in a sufficiently fluid state its materials adjusted themselves into the form of an oblate spheriod . . . which is exactly that necessary to counteract the tendency of a detached mass to move on such surface by virtue of the centrifugal force"; but he fails to note that the centrifugal force we have to deal with is not $V \cos\lambda$, to which the earth's figure is adapted, but $V^2 \cos^2\lambda \pm v^2 \sin^2\beta$, the substitution of which introduces the term F′ as above.

THE TWO-CYLINDER COMPOUND ENGINE IN WHICH THE STROKES ARE SIMULTANEOUS, OR CO-INITIAL AND CO-TERMINAL, WITH RECEIVER, CUSHION, CLEARANCE, ETC.

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Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

I.

PROBABLY the simplest form for this engine is that one much in use for pumping engines, and illustrated in the accompanying cut, Fig. 1, of a Worthington pumping engine. A is the high-pressure cylinder, B the low-pressure cylinder, and C the condenser.

Steam is admitted directly to A from the boiler; from A it is exhausted through the pipe shown partly obscured by the steam chests, directly to the large cylinder B, and from thence it is taken to the condenser.

The piston rods of A and B are both connected with one cross-head. When the pistons are both moving toward the left, high steam enters at the right-hand side of the piston A, while from the left side the steam passes freely through the connecting pipe to the right hand side of the piston B, the left side of B being open to the condenser.

It is evident that the pump might be removed and a crank and pitman substituted. The engine then becomes "rotative," that is, has a rotating shaft.

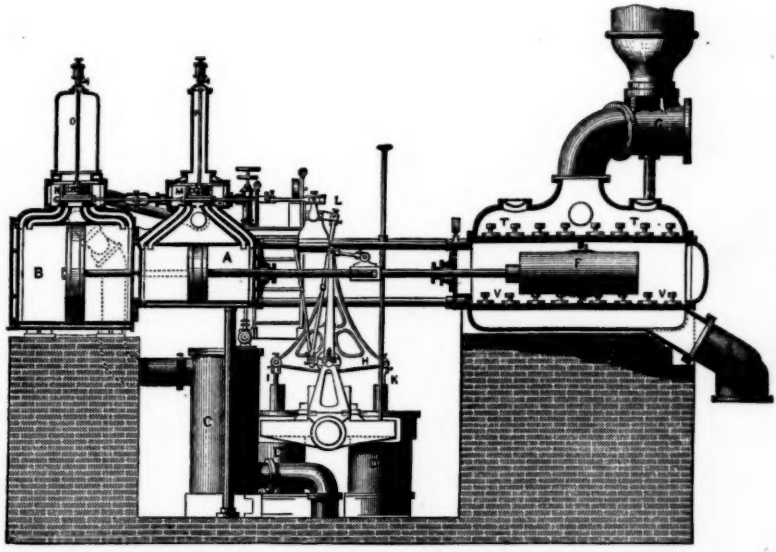

FIG. 1.—A WOOLF COMPOUND ENGINE WITHOUT INTERMEDIATE RECEIVER. STROKES SIMULTANEOUS

It is not essential that the pistons both move in the same direction at the same instant in a rotative Woolf engine, as would be the case in Fig. 1 made rotative; but one cylinder might be connected up with one crank, and the other cylinder with a second crank on the same shaft placed at 180° with the first crank. The pistons would then move simultaneously in opposite directions with strokes co-

initial and co-terminal in points of time.

Or instead of placing the cylinders both on one side of the shaft, they might be placed on diametrically opposite sides of the shaft. Then both could be connected to the same crank, or two cranks at 180° could be put one to each cylinder.

Again, the cylinders could be arranged at quartering points and the cranks likewise.

For the cylinders both at one side, many ingenious combinations of cylinders have been devised, some being of the trunk engine form, etc.

One arrangement is theoretically as economical as another, except for considerations of waste heat, and for large intermediate communicating pipes acting like receivers for remote cylinders. The best arrangement for a minimum of intermediate passage is where the cylinders are placed side by side, separated only by valves and acting on cranks at 180°. Then one piston moves opposite to the other and the steam passes over direct through short passages.

When the pistons are connected to cranks in such manner that the strokes are not co-initial and co-terminal, a considerable volume is required in an intermediate receiver. The engine then becomes the Wolff engine, the special considerations relative to which will not be entered upon here, but will be found treated in *Science Series*, No. 10.

In the study of any form or type of engine, the correct form of the diagram of the action of the steam in its passage through the cylinders is important; it must precede formulas, because formulas cannot be established until the steam action is perfectly understood. We will now attempt to trace the diagram for any form of the Woolf engine.

In Fig. 1, of Turnbull's Treatise, we have a theoretical diagram of a simple, one-cylinder, expansive condensing engine. The line AB is the axis of pressures or the line of zero volumes, and AE the axis of volumes or the line of zero pressures. To hereafter express this, we will only speak of the point A as the zero of pressures and volumes. On the supposition that the steam expands, according to the law of Mariotte, the expansion curve CD is a common hyperbola, such that the product of a pressure by its corresponding volume is equal to the like product for any other point.

A very convenient way for tracing this curve on a drawing board is as shown in Fig. 2. Take O as the zero of volumes and pressures. Then, suppose a to be any point in the expansion curve. Draw any straight line $abcd$, and make $cd=ab$. Then c is a point in the curve required. Then draw a second line through c and make $ab=cd$, and a is a second point in the curve. Any number of lines may be similarly drawn to find a like number of points. Thus, when any

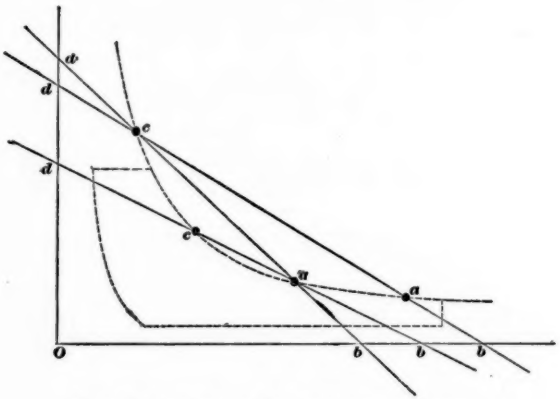

FIG. 2.—TO DRAW THE EXPANSION CURVE.

one point is given, as, for instance, C or D, Fig. 1, of Turnbull, any other points may be easily located through which to trace the curve CD. See also *American Machinist*, Dec. 16, '82; Wm. Lee Church.

But the actual steam expansion curve differs from Fig. 1, of Turnbull. It is apt to be steeper at the position near C, and flatter toward D. This is explained partly on the ground of partial condensation in the cylinder at the initial expansion, and of re-evaporation near the end of the expansion. In the average actual indicator diagram an hyperbola through C will very nearly strike D, for which reason this curve is mostly used in the examination of diagrams traced by the indicator. The position of the actual curve, however, will vary much with circumstances, and usually the higher the speed the lower will be the point D for a given point C. Expansion lines can therefore be drawn with a degree of approximation with the simple method of tracing given in Fig. 2.

Fig. 2 of Turnbull represents a theoretical indicator diagram for a Woolf compound engine. The part ABCDA is for the high-pressure cylinder; while the part ADEFA is for the low-pressure cylinder. The latter is very much smaller than the other; accounted for by the fact that the pressure is much lower in the low-pressure cylinder than in the other, while the length is made the same by the indicator. In studying these diagrams it is convenient to increase the length of the low-pressure diagram so that it is as many times longer than the high-pressure diagram as the low-pressure cylinder is larger in volume than the high-pressure cylinder.

Then if the areas of the high and low pressure diagrams are equal, the work developed by one cylinder equals that by the other.

Combined Diagrams.

To thus enlarge the low-pressure diagram and put the resulting combined diagram into the best shape for study, horizontal lines should be drawn through the diagram ADEF and increased in length by the ratio of the cylinder volumes as was first done by Rankin and as indicated in Fig. 3. Take AE = the volume of the high-pressure cylinder, and AF = volume of the low-pressure cylinder. Then, as in Fig. 2, of Turnbull, BCDH is the indicator diagram of the high-pressure cylinder, and AHDE of the low-pressure cylinder as taken by the indicator itself from the engine. Draw LKJ and make LJ = LK × ratio of cylinder volumes. Then J is a point in the new curve; any number of points in DJG may be thus found. Then BCDJGFA is the combined diagram, and the work developed per stroke of engine will be represented by it, also the work developed in each cylinder will be represented by its respective part of the area BDCH or

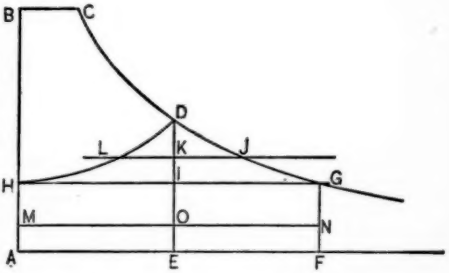

Fig. 3.—Combination of Diagrams.

AHDGF. The area AHDGF is equal to the area AHDE × ratio of volumes of cylinders as appears from the fact that in the transformation of this diagram the horizontal dimensions only are altered, and these in the ratio of cylinder volumes. This diagram supposes no clearance, no dead space between the cylinders, no cushioning, and no resistance to the motion of the motor fluid.

I.—Diagram of a Compound Engine without Receiver or Clearance, but with High-Pressure Cut-Off.

The action of the steam in passing through the engine whose diagram is presented in Fig. 3, may be thus traced, viz., BC is the admission line of steam at boiler pressure. At C the admission is arrested by a proper cut-off, when expansion goes on till the end of the stroke AE is reached for the high-pressure cylinder. The expansion curve CD has the point A for the zero of volumes and pressures; that is, for hyperbolic expansion the curve CD is to be constructed by aid of the lines AB and AF as explained in Fig. 2 from the lines A*b* and A*d*.

At the end of the stroke of the high-pressure cylinder the volume of steam admitted has become AE the volume of the high-pressure cylinder. Now a valve opens a passageway between the cylinders so as to discharge this steam from the full high-pressure cylinder into that end of the low-pressure cylinder at which the stroke is just beginning; but as there is no clearance, &c., this opening of the valve makes no change in the total volume of steam, the volume being still AE. Now the pistons are simultaneously to move and make their strokes, the steam to flow from the high-pressure cylinder into the low-pressure cylinder. In this act the volume enlarges from that of the high to that of the low-pressure

Now in the expansion line DG the steam expands from the volume AE to the volume AF, just as though the first or high-pressure cylinder had been long enough to have carried the expansion to that extent. From this it appears that the curve DG is simply the continuation of the curve CD, all drawn from A as the zero of volumes.

From this there appears to be no gain from compounding, because the diagram is the same as though the admission and expansion had all taken place in the low-pressure cylinder, itself and alone. The advantage in compounding is to be found outside of the diagram and will be considered elsewhere.

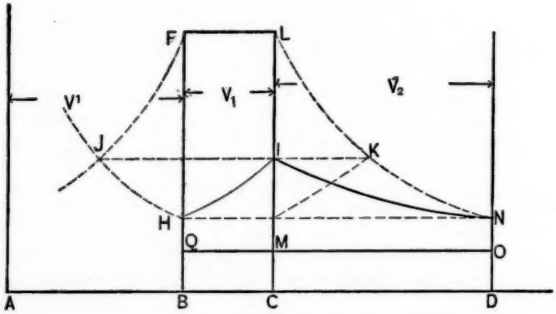

FIG. 4.

cylinder; that is, from AE to AF, Fig. 3, and the pressure of this expanding steam is the same at any instant in the two cylinders it being a back-pressure in the high and a forward-pressure in the low-pressure cylinder. Taking DG as the expansion line for this change of volume, AE to AF, we would have some line DLH of back-pressure for the high-pressure cylinder. This line begins and ends at the same height as the expansion line DG, in fact the lines throughout are at the same height at corresponding points L and J. At these points KL is the part of the stroke made by the high-pressure cylinder, LJ the part of stroke of the low-pressure cylinder, while JK is the corresponding increase of volume of the steam. The line MN may represent the back-pressure line of the low-pressure cylinder it being the line of pressure of the atmosphere or of the condenser.

II.—Diagram of a Compound Engine with no Clearance or Cut-Off, but with Receiver.

Let the volume of the high-pressure cylinder be BC, of the low-pressure cylinder be BD, and of the receiver AB. Now, supposing the engine in continuity of action, the diagram may be traced as follows: Represent the admission for full stroke by FL. At the end of the stroke the valve between the high-pressure cylinder and receiver opens when the steam in these parts commingle and the pressures equalize, the cylinder steam expanding and the receiver steam being compressed. As LF is the volume of the cylinder steam, this expansion will be along an expansion line FJ with the point C as the zero of volumes. The receiver steam will have the volume AB, and its pressure will be BH=DN=the terminal pressure of the low-pressure cylinder. Now as the "fresh"

steam FL is introduced, this receiver steam will be compressed along a compression line HJ with A as the zero of volumes. The point J of intersection of these curves gives the resulting pressure of the combined steam. The curve MK =HJ, giving K=J, might have been used. This pressure is that with which the low-pressure cylinder begins its stroke; and it should be laid off on the line at CI, because now the volume of steam is AC filling the receiver AB, and high-pressure cylinder BC. Now during the stroke this steam changes volume from AC to AD, because the high-pressure cylinder ejects its steam into the receiver, thus giving cause for a reduction of volume from AC to AB, while at the same time the low-pressure cylinder gives cause for an increase to AD, the difference being CD, the actual increase as stated. The expansion curve IN will be drawn with A as the zero of volumes, because AC is the lesser and AD the greater of the limiting volumes. The back-pressure line IH to the high pressure cylinder will correspond in height with IN, as explained in Fig. 3. The back-pressure line to the low-pressure cylinder is to be accounted for as to whether the exhaust is into a condenser or into the atmosphere.

Detrimental Effect of the Receiver.—This as a steam diagram differs from that of Fig. 3 by a depression of the expansion line IN from the dotted position LN. This engine with its receiver is thus seen to be less efficient than that of Fig. 3 by the absence of the area ILN. The smaller the receiver the less the depression or "drop" of the point I. For AB=*o*, I coincides with L. For AB =infinity the line IN is horizontal and straight. But the point N is fixed, its position being entirely independent of the volume of the receiver, and will always be found on the expansion line LN, the latter being drawn with B as the zero of volumes.

This important truth is apparent from the fact that at the end of the stroke of the low-pressure cylinder we discharge just the cylinder full of steam, the weight of which is the same as the weight of the steam admitted per stroke. Assuming the latter the same for two cases, one having a receiver and the other not; then it follows that the weight of the low-pressure cylinder full of steam exhausted per stroke is the same for both cases, so that if the small cylinders are of equal size the pressure of the contained steam at stroke terminations is the same for both; and also if the large cylinders are of equal volumes the pressures of their contained steam will be the same in both, thus making the points L and N coincide in both cases, both points being found on the line LN drawn with B as the zero of volumes and pressures as stated. This fact gives a ready means for locating the point N in tracing a diagram.

Comparison with an Indicator.—The diagrams taken directly by the application of an indicator to the engine will be HFLI for the high, and QHIM for the low-pressure cylinders. The relation of the work performed by the two cylinders can be obtained by measuring the areas just named with a planimeter, multiplying QHIM by the ratio of volumes and comparing with HFLI. But when the low-pressure diagram is expanded to QD, as in Fig. 4, the areas, and consequently the work of the two cylinders can be compared by sight, or by planimetric measurements.

The diagram that would be obtained by use of only the low-pressure cylinder as a simple engine, would be QFLNO, so that according to the diagrams the simple engine would be more efficient than the compound of Fig. 4 by the ratio

$$\frac{\text{QFLKNOQ}}{\text{QFLINOQ}}$$

Re-heating.—The receiver, which is responsible for the drop LI, appears by the diagram to be a detriment. This drop may, however, be more than compensated by using the receiver for a "re-heater" of the steam, by passing high steam through it in tubes. The intermediate steam may thus be raised in temperature to nearly that of the boiler steam, and consequently be somewhat superheated and made to work dry. The whole line IN may thus be raised to an extent nearly proportional to the elevation of the *absolute* temperatures of the steam by superheating, the absolute zero being a point about 493° F. below melting ice. (See lower part of Fig. 6.)

A small intermediate passage, such as shown in Fig. 1, will have the effect of a small receiver, and cause its corresponding drop LI.

The diagram Fig. 4 supposes no cut-off to either cylinder. There may, however, be one to both, as in the next case.

III.—Diagram of a Compound Engine with a Cut-Off to Each Cylinder, and with an Intermediate Receiver.

In Fig. 5 take BC = volume high cylinder, BD = B′D′ = volume of the low cylinder. AB = volume of the receiver, E = point of cut-off for the high cylinder, and N = the point of cut-off for the low cylinder. Also G′ = the point of release of the steam from the low-pressure cylinder, and QS = the back-pressure line of the final exhaust.

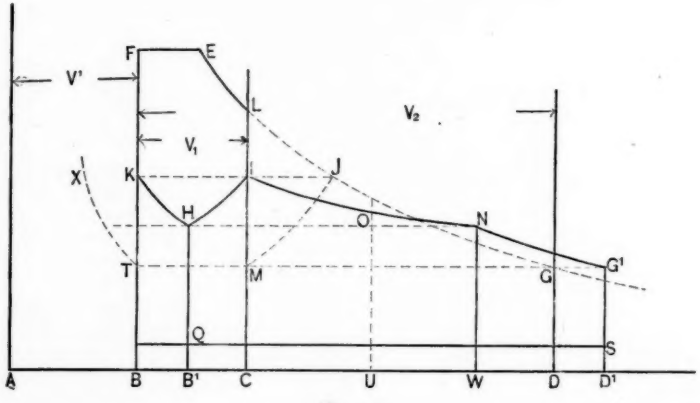

Fig. 5.

Now admit boiler steam FE, and cut-off at E, in the high cylinder BC. This steam expands along the expansion line EL, drawn with B for the zero of volumes and pressures. At the stroke terminal L, the valve between the high cylinder and receiver opens and the steam of these parts commingle; that of the former expanding along the line LJG with B for the zero of volumes, and of the latter along the compression line TX, with A for the zero of volumes. By turning over the curve TX, and transferring it to MJ, we obtain the intersection J, the height of which point above AD gives the resulting pressure of the commingled steam. A horizontal line through J gives I, the point from which lines of further action are to be drawn.

At this point of time the high cylinder piston is at the end of stroke, the low cylinder piston at beginning of stroke, and the volume of steam under action is that of AC, which fills the receiver and high cylinder in common. In the abscence of a low cylinder cut-off, the stroke of pistons now beginning would expand the steam from its present volume AC to the volume AD, and the pressure of release would be DG, the point G being on the line ELJ prolonged, as explained in Fig. 4. But suppose the low cylinder cut-off occurs at half stroke. This cut-off increases the average receiver pressure, so that the expansion line IN will now cut the line ELG and place N outside. To trace the curves G′NIHK, we find that the expansion line IN will be drawn from I, with A for the zero of volumes. To find the point N, suppose the cut-off in the low cylinder occurs at half stroke. It will also be at half stroke of the high cylinder, and the expanding volume between pistons at the instant of this cut-off will be the receiver AB + half the cylinder BC + half the cylinder BD. Take BU = ½ BD, and UW = ½ BC = BB′. Then N will be found at the point where AW = AB + BU + UW = the total volume expanding from I with the zero of volumes constantly at A.

Now when the steam is cut off at N, and at half stroke, the volume inclosed

in the low cylinder will be the half of that cylinder=B′W. Hence the expansion will go on from N to G′ with B′ for the zero of volumes until we have WD′ $=\frac{1}{2}$ BD$=\frac{1}{2}$ B′D′ completing the remaining half stroke. The line IH will be in common between the two diagrams from the same causes, as is DH, Fig. 3, or IH, Fig. 4, in common for those diagrams. Drawing from the half stroke point H, the line HB′, and also the back-pressure line QS, we complete the theoretical diagram for the low cylinder, HING′SQH. When the cut-off N occurs there is shut up in the receiver and the high cylinder the volume AB+BB′. The remaining stroke of the high cylinder will compress this to AB, giving the compression line HK, with a for the zero of volumes. Hence the high cylinder diagram is FELIHKF.

Effect on Distribution of Work of the Low Cylinder Cut-Off.—Were there no cut-off to the low-pressure cylinder, the expansion in this cylinder would terminate at G instead of at G′, and start from some point below I. From this it appears that the low cylinder cut-off has the effect to raise the mean pressure in the low cylinder and diminish it in the high cylinder. Hence, by applying a cut-off to the low cylinder we may increase the work performed in that cylinder, and diminish that performed in the high-pressure cylinder.

The terminal pressure D′G′ will be the same as though there were no cut-off to the low-cylinder, because the steam admitted is FE, and it must occupy the same volume B′D′=BD=the low cylinder pull at release, whether there be a low cylinder cut-off or not. Hence the terminal pressure D′G′=DG=CM will be

$$D'G'=BF\times\frac{FE}{BD}$$

if the Mariotte law of expansion is assumed to hold. By thus drawing the diagram Fig. 5, the relative or total areas or work of cylinders may be obtained.

To draw IH, take a zero of volumes to the right of C a distance

$$=AC\frac{V_1}{V_2-V_1}$$

In the present case, when the receiver is very large, the line KHIN comes to be nearly horizontal, and is quite so for an infinite receiver. When the receiver is zero in volume, the cut-off N must be dispensed with, and then the point I will rise to L.

IV.—Diagram of a Compound Engine with a Cut-Off to Each Cylinder, with a Receiver, and with Clearance and Cushion.

In Fig. 6 take $AB_1=V'$ = volume of the receiver, $BC=V_1$=volume of the high cylinder B_1B = volume of clearance to the high cylinder, B_1B_2 = volume of clearance to the low cylinder, and $B_2D=V_2$=volume of the low cylinder. Also in the high cylinder let E be the point of cut-off, L the release, IH the back pressure line for $\frac{3}{8}$ the stroke or till the cut-off occurs in the low cylinder, H*b* the cushion line against the receiver, and *bk* the cushion line against the clearance; and for the low cylinder, let I′N be the combined expansion line preceding cut-off at $\frac{3}{8}$ stroke, NG the expansion line subsequent to cut-off. SQ′ the back pressure line, Q′*c*′ the cushion against clearance, and H′I′ the counterpart of I′N. To better fix the ideas, let Fig. 7 represent the main features of the compound engine now considered. A being the high cylinder, B the low cylinder, C the receiver, F the boiler supply, G the exhaust, D the valves for A, and E the valves for B. The receiver includes all the space between D and E, the clearance of one end of A, all the space between D and the piston displacement for that end of A, and likewise the clearance of B, all the space between E and the piston displacement of B.

Now supposing the engine in continuity of action, let steam be cut off at E, Fig. 6, the clearance F′F, of course, being full of steam also. The expansion for the remainder of stroke will give the expansion line EL, drawn with the bottom of the clearance B_1, as the zero of volumes.

This is due to the fact that F′E and not FE is the original volume of the steam now expanding. At L, the high cylinder and its clearance are opened by a valve into the receiver, and the steam of these parts commingle, that of the former expanding along a line LJ, and of the latter being compressed along the line *e*′X= MJ; both taking a common pressure J at the intersection. The point M is understood in this to give the pressure in the

receiver and low-cylinder clearance at the instant the stroke is ended; and the valve between receiver and low cylinder is opened. The pressure M will be explained further.

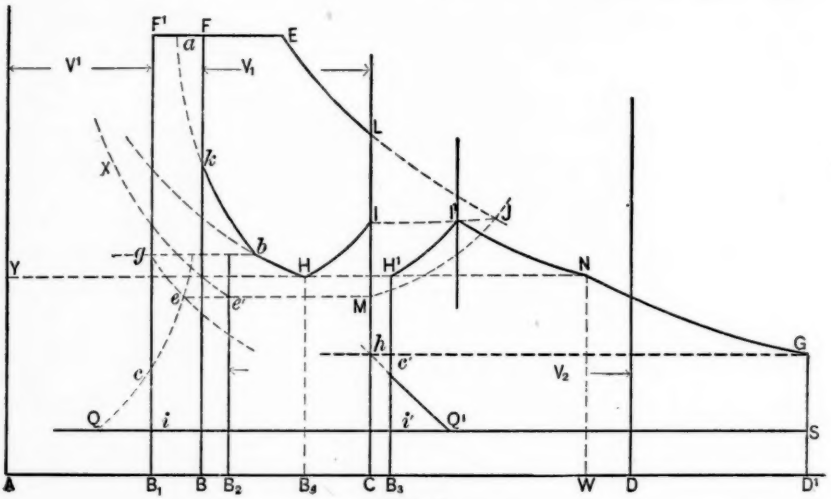

FIG. 6.

Drawing a horizontal line through J we obtain I for the initial back pressure line IH of the high cylinder V_1; and I' for the initial forward pressure of the low cylinder V_2, I' being distant from I by the clearance of V_2, viz. B_1B_2. I'H' is parallel to IH, that is, II'=HH'. We are now at the point of beginning of another stroke which will force the remaining steam from V_1 and fill V_2.

At this point of time the total volume of steam considered is that of the receiver, that of the high cylinder and its clearance, and that of the clearance of the low cylinder. It is $AB_1+B_1B+BC+B_2B_3$=a volume extending to the point I' where II'=B_1B_2. This volume will now expand along an expansion line I'N with A for the zero of volumes.

The point N is found by laying off the total volume for the time of cut-off in the low cylinder which has been taken above at $\frac{3}{8}$ the stroke. This fraction being the same for both cylinders we have H at $\frac{3}{8}$ stroke from I, so that YH = $AB_1+B_1B+\frac{3}{8}BC$=receiver+high cylinder clearance+$\frac{3}{8}$ high cylinder volume. To this add the low cylinder clearance B_1B_2=HH'=II'; and also add $\frac{3}{8}$ the volume of

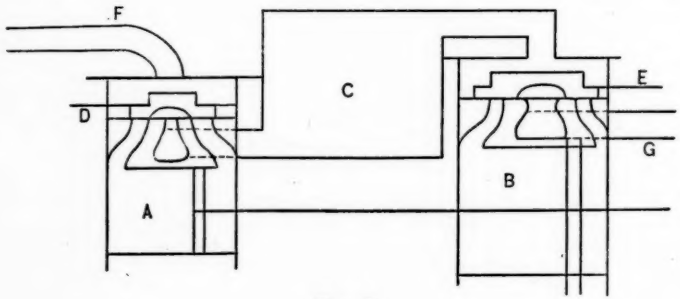

FIG. 7.

the low cylinder, or $\frac{3}{8}$ B$_2$D and we have the total volume YH+HH′+H′N=YN, H′N being equal to $\frac{3}{8}$ V$_2$. Beyond N the steam inclosed in the low cylinder will expand the remaining $\frac{5}{8}$ of stroke, giving the expansion line NG, drawn from B$_4$ as the zero of volumes; where NG, or D′W=$\frac{5}{8}$ the stroke, NH′, or WB$_3$=$\frac{3}{8}$ of stroke, and H′H, or B$_3$B$_4$=clearance.

The cushion line Q′C′ is due to the compression of a portion of the exhaust steam into the clearance, and is found by drawing Qc with B$_2$ as the zero of volumes, where Qi=Q′i′. The piston will compress the steam to c when further compression will result from the reversal of the valve and the commingling with it of the steam from the receiver. The pressure of this latter steam now admitted from the receiver is found from the point b where the high cylinder closes its valve for cushion, and after which the receiver is abandoned to itself till the end of the stroke is reached. This pressure b is B$_1g$, and as the steam is thus admitted from the receiver the pressures B$_1c$ and B$_1g$ combine at the intersection e of the line Qce drawn from B$_2$ as the zero of volumes, and the line ge drawn from A as the zero of volumes. The total volume now is AB$_2$ and pressure B$_2e$′, so that the line e′X of further compression can be drawn with A as the zero of volumes. Transferring this to MJ, and prolonging EL to J, we have the point of intersection J as that at which the steam now released from the high cylinder, combines with that in the receiver to a common pressure.

In the high cylinder and receiver there will be compression Hb, the curve being drawn with A as the zero of volumes. At b the valve between receiver and high-cylinder is supposed to close giving a compression line bk, which may be produced to a, drawn from B, as the zero of volumes.

The cushioning in the cylinders fills part of the clearances so that the steam admitted per stroke is aE at the pressure BF, and that exhausted is hG at the pressure D′G′, the curve Q′c′h being understood to be the same as Qce. The last statement enables us to find the pressure D′G; and it is=

$$D'G=BF.\frac{Ea}{G\overline{h}}$$

according to the Mariotte law of expansion.

For convenience in drawing the curve H′I′ we observe that the change of volume H′I′ is $\frac{3}{8}$ V$_1$, and the change of volume I′N is $\frac{3}{8}$ (V$_2$−V$_1$), so that H′I′ may be drawn from a zero of volumes taken at a distance to the right of B$_3$=

$$AW\frac{V_1}{V_2-V_1}.$$

The larger the receiver the more nearly horizontal becomes the line bHII′N, it being quite horizontal for an infinite re ceiver. On the other hand, the smaller the receiver the steeper become the declivities of that line and the more nearly I approaches to L, and the latter should be the cut off N. But I never coincides with L while clearance exists.

The cut-off N may be made useful in equalizing the amount of work performed by the two cylinders.

Relative Efficiencies.

In all the foregoing diagrams the theoretical diagrams have been sought, such as are needed for studying the relative efficiencies of engines, and not such as would be obtained by the indicator. Of several engines of different volumes of receiver, clearance, cushion, &c., of which the diagrams have the same heights BL, and the same steam volumes Ea; that engine which shows the greatest added area of both diagrams has the highest efficiency. Such efficiency can be investigated graphically as above, and that method is probably the most practical, because analytical formulas for such cases as the last two above, become so excessively complex as to make more trouble and labor than will the drawing board and planimeter.

Doctoring of the Diagrams for Speed, Condensation, Re-Heating, etc.

The faster the engine runs and the greater the amount of work done the greater will be the resistance to the fluid through the passages from the boiler through the engine to the condenser or atmosphere. This resistance causes a lowering of the admission line FE, a raising of the exhaust line Q′S, and a vertical separation of the lines 1Hbk and H′I′NG, of Fig. 6, and likewise for the

other cases an approximation to the amounts of these effects can be obtained by the aid of the formulas for flow through orifices and pipes, which are,

For orifices

$$v^2=\frac{q^2}{a^2}=2u^2gh=64u^2h \text{ nearly,}$$

and for pipes or passages

$$v^2=\frac{q^2}{a^2}=\frac{2ghd}{fsl}=1100.\frac{hd}{sl} \text{ nearly;}$$

where the head h may be obtained from the pressures and density of steam or air by the formula

$$h=\frac{p'-p''}{\delta}$$

In these formulas v=velocity of fluid through orifice or passage, q=the cubic feet of fluid per second, a=area of cross section, orifice or passage, s=perimeter of same section, l=length of passage, all in feet, u = a coefficient of velocity through orifice, =0.82 for orifice of entry to a tube, or=0.62 for an orifice through a thin partition, f=coefficient of friction=about 0.006, $p'-p''$=the fall of pressure lbs. per square foot in going through the orifice or passage, and δ=the density or weight per cubic foot of the flowing fluid. Its value may be obtained from Table D by dividing the weight of a cubic foot of water (about 62 lbs.) by the value in the volume column of table corresponding to the pressure for which δ is sought.

The formulas apply only for comparatively small falls of pressure, such as that from boiler to steam-chest, or from steam-chest to cylinder.

In selecting the value of δ, care should be taken to find its true value. In wet steam the moisture should be included. From this cause the value of δ may rise to two, or even three times its value for dry steam.

If w=velocity of piston in feet per second, and A=area of piston in square feet, we have

$$q=Aw$$

for steam passages leading to and from cylinders. Introducing this, and taking u at .8, also eliminating h, we obtain the practical formula for entry to passages, and for short passages

$$\frac{A^2w^2}{a^2}=41\frac{p'-p''}{\delta}$$

and for passages only

$$\frac{A^2w^2}{a^2}=11000.\frac{a}{sl}.\frac{p'-p''}{\delta}.$$

Combining the two formulas into one for application to passages whose lengths vary from 10 to 300 or 400 times their thickness, we obtain

$$\frac{A^2w^2}{a^2}\left(1+.0074\frac{sl}{a}\right)=41\frac{p'-p''}{\delta}$$

It is generally best to assume a value for the "a" in the parenthesis of the last formula.

The rounding of the corners of the diagrams can only be done by the judgment of the engineer. The greater the speed of the engine the earlier must be the release, in order that the release end of the diagram shall not be too sharp at the top corner at the expense of excessive curtailing of the lower corner. The rounding of the cut-off corners must be done with reference to both the speed of engine and rapidity of closure of cut-off valve.

Considerable condensation is liable to occur in the high-pressure cylinder when it has an early cut-off, so that the expansion line for it may fall with undue rapidity. This may be avoided in a measure by use of the steam jacket. The condensed steam flowing from this cylinder will accumulate in the receiver unless disposed of by escape traps, or by reheating, the latter process consisting of placing hot surfaces in or about the receiver. These heating surfaces may be tubes passing through and containing high steam from the main boiler, or from a second boiler, which may be at even a higher temperature and pressure than the steam in the first named one. The steam may thus become superheated for the low-pressure cylinder. If now no water has been drawn off, but if all the contents from the high-pressure cylinder is changed into superheated steam, then the expansion curve for the low-pressure cylinder may first be drawn on the supposition of dry steam, and then to be raised nearly to the extent of the elevation of the absolute temperature of that steam above the temperature due to its pressure as dry steam. (See Fig. 14). The latter temperature is given by tables of the properties of steam. (See Table D in Turnbull's Treatise.) If any con-

densed steam is trapped out, the expansion curve of the low-pressure cylinder must, provided the steam admitted be dry, be below that due to dry steam.

Precise Form of the Expansion and Compression Curves.

In a diagram such as that of Fig. 5 or Fig. 6, the steam curves differ in character. From the standpoint of thermodynamics, the curve EL, for instance, is an adiabatic for initial dry steam. Steam thus expanding fogs up with particles of condensed steam forming throughout the mass, and a rainstorm begins in the cylinder at each stroke. That steam does its full work due to expansion, and EL falls more rapidly than the hyperbola. But from L to J the steam does but partial work, viz., that under the compression curve MJ. The action LJ and MJ, of combining, is "isodynamic," that is, no external work is performed. Both these curves may therefore be drawn as isodynamic curves, they being very nearly hyperbolic.

If the steam is reheated to superheat in the receiver, the line IN will be the adiabatic for superheated steam, also the line NG. Such lines fall much more rapidly than the hyperbola. Compression lines, as in cushioning, rise more rapidly than the hyperbola, because the steam is superheated by the compression, and if any water is present, there may be re-evaporation.

The equations of all these curves may be expressed approximately by the equation,

$$pv^x = \text{constant}.$$

in which, for the Mariotte law of expansion, $x=1$. To supply the constant we may put the equation in the form

$$\frac{p}{p_1} = \left(\frac{v_1}{v}\right)^x \quad . \quad . \quad . \quad . \quad (1)$$

An equation which is approved for ordinary purposes by high authority, and will be adopted in the present case.

Table E, next column.

This table and the equation will give us the equation of any curve desired.

In these we not only have authority for a variety of values of x, but in m the "steam quantity" ∞ suggests that the value of x may be determined even by estimation from such facts as may effect ∞. Accordingly, for an expansion where only partial work of expansion is performed, x may be found to lie between $\frac{4}{3}$ and 1.0456 for superheated steam. When $\infty = 1$ we have $x = 1.135$. It is to be observed, however, that the form of curve, according to equation (1), is dependent on the value of the exponent, so that the general equations may be considered as suitable for any forms of these lines.

Table E:—Of Values of x, and Authority.

Values of $x=$	Adiabatic expan. Initial saturation, s. m	Curve of saturation.	Adiabatic for superheated steam. a	Isodynamic for superheated steam. n
Rankine.	$\frac{10}{9}=1.11111$	$\frac{17}{16}$, and 1.0646	1.3	Not given.
Cotterill.	$1.035+\frac{\infty}{10}$	$\frac{17}{16}$, and 1.0646	"	Bet. s and 1
Zeuner...	" "	1.0646	$\frac{4}{3}=1.3333$	1.0456
Röntgen.	" "	"	"	"

The table shows a very considerable range in the value of x, some going so far from $x=1$, as to advise the abandonment of the Mariette law of expansion in which $x=1$. An example of carefully computed volumes for several curves and chosen pressures will serve to illustrate the departure of the expansion lines of different kinds from each other.

Table F.—Example. Steam.

Absolute pressures. lbs.	Common hyperbola. vols.	Saturation curve. vols.	Adiabatic curve. vols.
23.	122.0	122.0	122.0
50	56.1	58.3	60.6
83	33.8	36.5	38.4

Thus for these curves running through a point at 23 lbs., and volume 122, at about a threefold greater pressure the saturation curve deviates 8 per cent. and the adiabatic curve 14 per cent. in volume from the hyperbola.

But as the curve for which $x=1$, viz., the common hyperbola drawn by its asymptotes, is so very convenient for tracing, (see Fig. 2,) and falls so near the required curves, we are lead to look for some rule by which to "correct over" from the hyperbola to the curves sought. Such rule was given by the writer in the *American Machinist*, for Feb. 10, 1883, the convenience of which assures the desirability of the following abstract here:

Some engineers judge of the steam action, leakage of piston, valves, &c., by a simple reference to the hyperbola.

Then what here follows could be dispensed with, but the more fastidious will probably wish to compare with other curves, which can be easily laid off from this hyperbola by correction, or difference quantities as follows, as hinted by Cotterill, page 341.

Differentiate the equation given above, regarding x and v as variable. The result can be reduced to

$$\frac{dv}{v}=\frac{dx}{x}\text{ hyp. log. }\frac{v_1}{v}=\frac{dx}{x}\times k$$

in which v_1 is one volume, as, for instance, a, Fig. 8, and v, the other, for any point as c; and k, a coefficient. The logarithmic part, or coefficient, k, may be tabulated, and becomes a convenient coefficient, or factor, for the second member of the equation, or for the quantity $\frac{dx}{x}$ which quantity is definitely known as soon as x is decided upon. For instance, take $x=\frac{1}{9}^0$ for the adiabatic curve, it being 1 for the common hyperbola. Then dx will be the difference of these values, or $\frac{1}{9}^0-1=\frac{1}{9}$, and $\frac{dx}{x}=\frac{1}{10}$.

If the coefficient were 1, then the correction dv would be a tenth of v.

More definitely, suppose in Fig. 8, OB$=v_1$ and OA$=v$; then the correction is $ce=\frac{1}{10}$ OA, for the values just named.

The values for the coefficient, k, are given in the table G.

TABLE G:—OF COEFFICIENT k.

$\frac{v_1}{v}$	k		$\frac{v_1}{v}$	k
1.1	.095	..	3.3	1.194
1.2	.182	..	3.4	1.224
1.3	.262	..	3.5	1.253
1.4	.336	..	3.6	1.281
1.5	.405	..	3.7	1.308
1.6	.470	..	3.8	1.335
1.7	.531	..	3.9	1.361
1.8	.588	..	4.0	1.386
1.9	.642	..	4.2	1.435
2.0	.693	..	4.4	1.482
2.1	.742	..	4.6	1.526
2.2	.788	..	4.8	1.569
2.3	.833	..	5.0	1.609
2.4	.875	..	5.5	1.705
2.5	.916	..	6.0	1.792
2.6	.955	..	6.5	1.872
2.7	.993	..	7.0	1.946
2.8	1.030	..	7.5	2 015
2.9	1.065	..	8.0	2.079
3.0	1.099	..	8.5	2.140
3.1	1.131	..	9.0	2.197
3.2	1.163	..	9.5	2.251
		..	10.0	2.303

TABLE H:—OF VALUES OF $\frac{dx}{x}$.

For the saturation curve,

$$x=\frac{17}{16},\text{ and }\frac{dx}{x}=\frac{1}{17}=.0588.$$

For the adiabatic curve,

$$x=\frac{10}{9},\text{ and }\frac{dx}{x}=\frac{1}{10}=0.1.$$

For the adiabatic curve, $x=1.035-.1\infty$ and

$$\frac{dx}{x}=\frac{.035-.1\infty}{1.035-.1\infty}.$$

For the isodynamic curve, $x=1.0456$, and

$$\frac{dx}{x}=\frac{.0456}{1.0456}=.0436.$$

For the adiabatic of steam gas, $x=1.3$, and

$$\frac{dx}{x}=\frac{.3}{1.3}=.2308.$$

For the adiabatic of gases, $x=1.408$, and

$$\frac{dx}{x}=\frac{.408}{1.408}=.29.$$

To illustrate the use of these tables, suppose ac, Fig. 8, to be the hyperbola of reference (the common hyperbola), with Ba=23 lbs., Ac=83 lbs., in absolute pressures; and OB, the volume 122, as in Table F. Then the volume OA, will be 33.8 for the common hyperbola.

Hence for $v_1=122$, and $v=33.8$; $\frac{v_1}{v}=3.61$.

In Table G, we look under $\frac{v_1}{v}$ for the value 3.61 and find the nearest to be 3.6, but 3.61 is one-tenth the way over toward 3.7. Consequently we look for that value of k, which lies one-tenth the way from 1.281 toward 1.308, and obtain $1.284=k$. For k, this answers for all the curves.

Now in Table H, we find, for adiabatic expansion of steam,

$$x=\frac{10}{9}\text{ and }\frac{dx}{x}=0.1$$

consequently

$$\frac{dx}{x}k=0.1\times1.284=.1284=\frac{dv}{v}.$$

The correction is therefore $dv=v\times.1284$ $=33.9\times.1284=4.9=ce$, Fig. 8. This added to the volume v=OA gives

$$v+dv=33.8+4.8=38.7=fe,$$

a value which differs less than 1 per cent. from the computed value 38.4 in Table F.

As a second case, suppose the expansion be according to the saturation curve, when by Table H

$$\frac{dx}{x}=\frac{1}{17},$$

then

$$\frac{dx}{x}k=\frac{1}{17}\times 1.284=.0745$$

and $dv=v\times.0745=33.8\times.0745=2.86$. This added to the volume v gives

$$v+dv=33.8+2.86=36.7$$

a value which differs but slightly from the calculated value 36.5 at the foot of the second column of Table F.

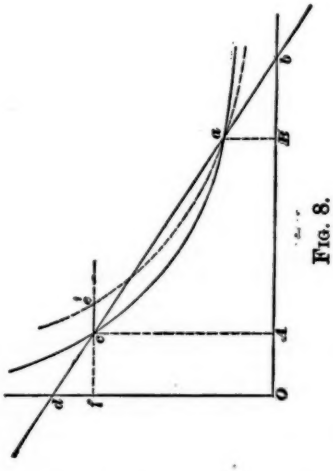

Fig. 8.

In these calculations we observe that the volume v, with which to multiply, and to which to add, is the one which is to be corrected, viz., in this case we seek the correction $c\,e$, Fig. 8, and hence the volume v is to be taken as AO.

But the rule may be applied the other way. That is to say, we may make c the point of intersection of the two curves, and correct the volume BO. In that case k is to be found as before, and given the contrary sign. In fact the whole quantity $\frac{dx}{x}k$ will be the same as before, except for the contrary sign; if the volumes on the common hyperbola are the same, viz., 33.8 and 122. But in this calculation we should multiply by the volume BO, because the correction is for this volume. That is, the correction is $122\times.1284=15.7$ for the adiabatic expansion, a quantity which, by the accurate method, is found to be 16.6, differing be less than one per cent. or the value of BO to be corrected. For the saturation curve the correction is $122\times.0745$, &c.

For points beyond a the correction is subtractive instead of additive, and multiply tabular quantity by the greater instead the lesser volume; that is, by the volume to be corrected.

Let us apply the first rule to correct the hyperbolic volume 56.1, to the adiabatic volume 60.6, for pressure 50 lbs. absolute; the final volume and pressure being 23 lbs. and 122 respectively.

Dividing greater by lesser volume we get $\frac{122}{56.1}=2.175$. For this ratio of volumes we find k from Table G to be $k=.777$. For the present adiabatic expansion, Table H calls for $\frac{1}{10}$ giving .0777. Multiplying by the volume 56.1 gives the correction of 4.47. Adding this to the volume 56.1 to be corrected, we obtain $56.1+4.47=60.6$; or, in this case, exactly the value given by the logarithmic calculation of Table F.

This method of corrections by which the curves desired can be easily obtained from the simple hyperbola, will greatly facilitate the graphical method of accurately calculating the relative efficiencies or the relative area of diagrams, or of work performed in the cylinders of compound engines.

Actual Efficiency.

The actual efficiency of the engine is obtained by dividing the whole ft. lbs. of work performed in both cylinders per stroke by the dynamical value of the heat required to produce the steam consumed for that stroke.

Thus, in Fig. 6 the work performed per stroke in ft. lbs. is obtained by multiplying the mean pressure lbs. per square inch in a cylinder by the piston area in square inches, and by the length of stroke in feet, and adding the products thus obtained for all the cylin-

ders. Call this quantity U. The mean pressure is obtained by taking the mean height of the diagrams in the usual way, the scale of heights being that of pressures per square inch. To find the mean height of a diagram by aid of the planimeter, find the area by the instrument and divide that area by the length of the diagram expressed to the proper unit. If the instrument gives the area in square inches divide the area by the length in inches, and lay off the result as a height in inches on the diagram. A horizontal line drawn through this point is the line of mean pressure, and that pressure is to be measured by the scale of pressures.

The steam consumed per stroke has already been stated to be Ea, Fig. 6, which must now be measured with the proper scale. Measured by the same scale which makes BC the volume of the high cylinder in cubic feet, gives the quantity of steam $e\ a$ in cubic feet, as desired. Call this V′.

The heat required to produce the steam used at a stroke of the high-pressure cylinder will be the total heat of evaporation from the temperature of feed water, and at the temperature of boiler pressure.

Let V_1' = the volume of steam required per stroke of high cylinder in cubic feet.

D_1 = the weight per cubic foot of the steam as supplied to the engine.

U = the ft. lbs. of work performed per stroke of engine.

H_1 = the dynamical value of the total heat of evaporation per pound from 32° F. at the temperature of boiler pressure steam; that is, the heat to raise the temperature of the water from 32° F. to the temperature of the steam in boiler, added to the latent heat of evaporation at the latter temperature. (Convenient values are given for this in the tables of *Rankine's Steam Engine.*)

t_1 = the actual temperature of the feed water.

J = Joule's equivalent, = 772 ft.-lbs.

Then the total heat consumed per high-pressure cylinder full of steam in dynamical value, or ft.-lb. units, is

$$H = V_1' D_1 \left(H_1 - J(t_1 - 32°) \right) \quad . \quad (2)$$

and the efficiency $= \frac{U}{H}$ . . . . (3)

Area of Diagrams by Calculation.

Some of the more simple diagrams may be more readily calculated than drawn on a drawing-board and measured.

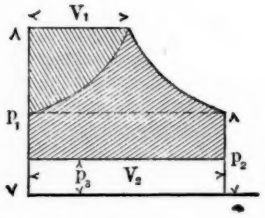

Fig. 9.

For such a diagram as shown in Fig. 9 the area of that portion falling under the expansion line between two verticals and above the vacuum line for one pound of steam in the usual notation is

$$\int p dv \quad . \quad . \quad . \quad . \quad . \quad (a)$$

where p, as shown, is the specific pressure of the steam, or absolute pressure per unit surface; usually pounds per square foot; v_1 = the specific volume, or volume per unit weight; usually cubic feet per pound; and where p is the varying pressure under the curve

$$\int p dv - p_3 v_2.$$

This is for one pound, and not for the actual volumes V_1 and V_2. Hence the area in (a) is simply *like* that designated in Fig. 9, but not equal it.

But in the present case it will probably be most convenient to apply our reasoning to the actual volumes V_1, V_2, and V′ of the high cylinder, low cylinder and receiver respectively.

For the present convenience let A = the area of the high-pressure piston, and L the length of its stroke. Then

$$V_1 = AL,$$

or multiplying through by P

$$P_1V_1 = P_1AL = \text{actual area under the admission line} \quad . \quad . \quad . \quad . \quad (4)$$

Similarly below the expansion line

$$\text{actual area} = \int_{L_1}^{L_2} PA\,dL \quad . \quad . \quad . \quad (5)$$

if L_1 = length of the admission line, and L_2 = length of the exhaust line. The pressure P is here variable, but according to (1), the zero of volumes being noted, is

$$\frac{P}{P_1} = \left(\frac{L_1}{L}\right)^x = \left(\frac{V_1}{V}\right)^x$$

Hence (5) becomes

$$\text{actual area} = AP_1L_1^x \int_{L_1}^{L_2} \frac{dL}{L^x}$$

$$= AP_1L_1^x \frac{1}{1-x}\left(L_2^{1-x} - L_1^{1-x}\right);$$

or, since $L_2 = L_1 + l$, where l is the length under the expansion line.

Actual area

$$= AP_1L_1^x \frac{1}{1-x}\left\{(L_1+l)^{1-x} - L_1^{1-x}\right\}$$

$$= AP_1L_1 \frac{1}{x-1}\left\{1 - \left(\frac{L_1}{L_1+l}\right)^{x-1}\right\}$$

$$= \frac{P_1V_1}{x-1}\left\{1 - \left(\frac{V_1}{V_2}\right)^{x-1}\right\}$$

$$= P_1V_1 \frac{1 - \frac{1}{r^{x-1}}}{x-1} \quad . \quad . \quad . \quad (6)$$

that is, the area under any expansion or compression line is equal the rectangle to the pressure and volume of the highest point in the curve multiplied by the function of the ratio r, of expansion, and of the exponent x as shown.

To express the area in terms of the rectangle to the pressure and volume of the lowest part of the expansion curve we have, according to eq. (1).

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^x = r^x$$

and

$$\frac{V_2}{V_1} = r$$

$$\therefore \quad P_1V_1 = P_2V_2r^{x-1}$$

and hence we may write in place of (6)

$$\text{actual area} = P_2V_2 \frac{r^{x-1} - 1}{x-1} \quad . \quad . \quad (7)$$

For the particular case $x=1$ the equation becomes inapplicable. But for this case the general integral gives the

$$\text{Actual area} = P_1V_1 \text{ hyp. log. } r \quad . \quad (8)$$

which is equal to the rectangle to the highest point of the curve, multiplied by the hyperbolic logarithm of the rate of expansion. These logarithms are found in Table B.

As x is here $=1$, we have

$$P_1V_1 = P_2V_2$$

and hence we may put in place of (8) when more convenient,

$$\text{Actual area} = P_2V_2 \text{ hyp. log. } r \quad . \quad (9)$$

Applying these to Fig. 9, observing that it is the diagram of a compound engine in which there is no clearance nor receiver, and no cut-off to either cylinder, we have to add the rectangle P_1V_1 and deduct the rectangle below the exhaust line P_2V_2, and hence, calling the work performed by this engine per stroke U, we have, by application of (6),

$$U = P_1V_1 + P_1V_1 \frac{1 - \frac{1}{r^{m-1}}}{m-1} - P_2V_2$$

$$= \frac{P_1V_1}{m-1}\left(m - \frac{1}{r^{m-1}}\right) - P_2V_2 \quad . \quad . \quad (10)$$

P_2 being the back pressure.

This is the same expression as obtained for a single cylinder engine, the whole expansion taking place in the one cylinder.

The exponent x is probably m in this instance for the reason that there is no isodynamic "drop" in the pressure between the cylinders.

Similarly for the case $x=1$ we have, by (8),

$$U = P_1V_1(1 + \text{hyp. log. } r) - P_2V_2 \quad (11)$$

I. Case of Fig. 3.

Calling the volume of admission BC = V_1', and the ratio of expansion in the high-pressure cylinder r_1, we have

$$\frac{V_1}{V_1'} = r_1$$

V_1 being the volume of the high cylinder,

and to be so regarded in every application. Hence V_1' in the present case is to replace V_1 of Eq. (10) or (11). Hence, our expression for the whole work per stroke is

$$U=\frac{P_1V_1}{r_1(m-1)}\left(m-\frac{1}{r^{m-1}}\right)-P_2V_2 \quad . \quad . \quad (12)$$

r_1 being the ratio of expansion in the high-pressure cylinder itself, and r the ratio of the entire expansion C to G, also P_1=the boiler pressure (absolute), and V_1 the volume AE of the high-pressure cylinder.

The work performed in the low-pressure cylinder alone, according to (6), is

$$AHDGFA-P_2V_2=EDGFE\frac{AF}{EF}-P_2V_2$$

$$=\frac{AE\times ED}{m-1}\left\{1-\frac{1}{\left(\frac{AF}{AE}\right)^{m-1}}\right\}\frac{AF}{EF}-P_2V_2$$

$$=\frac{P_1V_1}{r_1{}^m(m-1)}\left\{1-\left(\frac{V_1}{V_2}\right)^{m-1}\right\}\frac{V_2}{V_2-V_1}-P_2V_2$$

The work performed in the high-pressure cylinder is, of course, the difference between the last equation and (12).

For the case $x=1$, we have

$$U=\frac{P_1V_1}{r_1}(1+\text{hyp. log. } r)-P_2V_2$$

and the work performed in the low-pressure cylinder according to (8) is

$$=AE\times ED\frac{AF}{EF}\text{ hyp. log. }\frac{AF}{AE}$$

$$=\frac{V_1P_1}{r_1}\frac{V_2}{V_2-V_1}\text{hyp. log. }\frac{V_2}{V_1}$$

II. Case of Fig. 4.

As to the exponents x for this case, the combined expansion and compression LJ and HJ is isodynamic, that is, unaccompanied with external work, and the steam is probably slightly superheated, so that for the fall from L to I the proper value for x is probably n, or nearly it. Granting this, then the x for the other expansion should be a, or between a and m, as may be judged by the engineer in particular cases. With these values of x, we have

$$\frac{P_i}{P_n}=\left(\frac{V_2+V'}{V_1+V'}\right)^a$$

$$\frac{P_1}{P_i}=\left(\frac{IJ}{V_1}\right)^n$$

$$\frac{P_n}{P_i}=\left(\frac{IJ}{V_2}\right)^a$$

whence

$$\frac{CL}{CI}=\frac{P_1}{P_i}=\left(\frac{V_2}{V_1}\cdot\frac{V_1+V'}{V_2+V'}\right)^n$$

$$\frac{CL}{DN}=\frac{P_1}{P_n}=\left(\frac{V_2}{V_1}\right)^n\left(\frac{V_2+V'}{V_1+V'}\right)^{a-n}$$

by aid of which the diagram can be accurately constructed. The subscripts here refer to the Fig.

For an infinite receiver $V'=\infty$; and the equations for pressures reduce to

$$\frac{P_1}{P_i}=\frac{P_1}{P_n}=\left(\frac{V_2}{V_1}\right)^n \quad . \quad . \quad . \quad (13)$$

By application of Eq. (7), observing that for IN the ratio of expansion is

$$=\frac{V_2+V'}{V_1+V'},$$

we have,

$$U=$$

$$P_1V_1+P_n\frac{V_2+V'}{a-1}\left(\left(\frac{V_2+V'}{V_1+V'}\right)^{a-1}-1\right)-P_2V_2$$

and eliminating P_n

$$=\left\{\begin{array}{l}1-P_2V_2\\ +\left(\frac{V_1}{V_2}\right)^n\frac{V_2+V'}{V_1(a-1)}\left(\left(\frac{V_2+V'}{V_1+V'}\right)^{a-1}-1\right)\end{array}\right\} \quad (14)$$

If $V'=0$ the receiver is dispensed with, and this case reduces to that of Case I. The above then for $n=a$ reduces to

$$U_1=P_1V_1\left\{\frac{a}{a-1}-\frac{1}{a-1}\left(\frac{V_1}{V_2}\right)^{a-1}-\frac{P_2V_2}{P_1V_1}\right\} \quad (15)$$

which is the same as (10) if a is changed to m, as it should be for the present supposition where $V'=0$ of no isodynamic expansion nor consequent superheating. The change in diagram, Fig. 4, due to making $V'=0$, consists in the raising of the point I up to L while N remains fixed. The diagram then agrees with Fig. 9 below.

When $x=1$ we have for Fig. 4 and Equation (9)

$$\text{area CIND}=P_n(V_2+V')\text{hyp. log.}\frac{V_2+V'}{V_1+V'}$$

. . . . . (16)

Adding BCLF and deducting for back pressure we have for the work performed per stroke of the engine

$$U=$$

$$P_1V_1+P_n(V_2+V')\,\text{hyp. log.}\frac{V_2+V'}{V_1+V'}-P_3V_3$$

$$=P_1V_1\left\{1+\left(1+\frac{V'}{V_2}\right)\text{hyp. log.}\frac{V_2+V'}{V_1+V'}\right\}$$

$$-P_3V_2 \quad . \quad . \quad . \quad . \quad (17)$$

It is to be observed that the zero of volumes for the expansion IN is at A, and for the curve LN we have, for $x=1$,

$$P_nV_2=P_1V_1$$

If $V'=0$ we have Eq. (11), as we evidently should.

IIA. Case of Cut-Off and Expansion in the High-Pressure Cylinder, Together with a Receiver.

Fig. 10 is the diagram representing the present case, where BC is the volume of the high-pressure cylinder, BD the volume of the low-pressure cylinder, and AB the volume of the receiver.

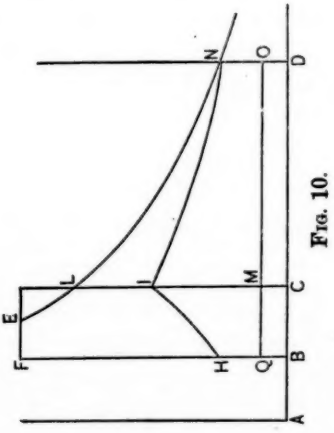

Fig. 10.

The admission at boiler pressure P_1 is from F to the cut-off at E. From E to L is the expansion curve answering to the expansion in the high-pressure cylinder, L to I is the fall of pressure due to exhaust from this cylinder into the receiver AB, and IN is the expansion curve for the forward stroke of the low-pressure cylinder, the zero of volumes for which curve is at A, because at the beginning of the stroke the volume AC is that which fills the receiver and high-pressure cylinder, while at the end of the stroke the same steam has the volume AD of the receiver and low-pressure cylinder.

The work done in the high-pressure cylinder per stroke is represented by the area HFELIH, while the same for the low-pressure cylinder is QHINOQ, OQ being the exhaust line.

Let r_1 = ratio of expansion in the high-pressure cylinder, giving

$$r_1=\frac{BC}{EF}$$

An expression for the

$$\text{area BCLEFB}=\frac{BF\times FE}{m-1}\left(m-\frac{1}{r^{m-1}}\right)$$

$$=\frac{P_1V_1}{r_1(m-1)}\left(m-\frac{1}{r^{m-1}}\right) \quad . \quad . \quad (18)$$

is given in (10).

Referring to the equation preceding (14), we see that it may be modified to represent the work per stroke in the present case by substituting (18) for the first term, and by substituting $P_1\div r_1^m$ for "P_1" of the second term, because there "P_1" = the terminal pressure CL, Fig 10, while BF must stand for P_1. Making these changes in (14) we have, for the work per stroke of both cylinders for the case now considered,

$$U=\frac{P_1V_1}{r_1(m-1)}\left(m-\frac{1}{r^{m-1}}\right)+$$

$$\frac{P_1V_1}{r_1^m}\left(\frac{V_1}{V_2}\right)^n\frac{V_2+V'}{V_1(a-1)}\left(\left(\frac{V_2+V'}{V_1+V'}\right)^{a-1}-1\right)$$

$$-P_3V_2 \quad . \quad . \quad . \quad . \quad (19)$$

$$=P_1V_1\left\{\frac{m-\frac{1}{r^{m-1}}}{m-1}\right.$$

$$+\frac{V_2+V'}{V_1r_1^m(a-1)}\left(\frac{V_1}{V_2}\right)^n\left(\left(\frac{V_2+V'}{V_1+V'}\right)^{a-1}-1\right)$$

$$\left.-\frac{P_3V_2}{P_1V_1}\right\} \quad . \quad . \quad . \quad . \quad (20)$$

The work performed in the low-pressure cylinder is found by taking the last two terms of (19) for the area MINO, multiplying it by BD, and dividing by CD, that is,

$$\text{area QHINOQ} = \text{MINO} \times \frac{V_2}{V_2 - V_1} \quad . \quad (21)$$

For the case $x=1$ we have the 1st term of (11) as an expression for the area of the diagram of the form BCLEF, Fig. 10, where the "V_1" in (11) is =FE. But here $BC = V_1 = r_1 FE = \text{"}V_1\text{"} r_1$, whence

$$\text{"}V_1\text{"} = \frac{V_1}{r_1}.$$

Putting this value of "V_1" into the first term of (11), and we have

$$BCLEFB = \frac{P_1 V_1}{r_1}(1 \times \text{hyp. log. } r_1) \quad . \quad (22)$$

The area for CIND is

$$AD \times DN \text{ hyp. log. } \frac{AD}{AC}$$

and $BD \times DN = BC \times CL = V_1 \times CL.$

But $r_1 \times CL = P_1 = BF,$

and $$DN = \frac{P_1 V_1}{r_1 V_2}.$$

Hence the area

$$CIND = \frac{P_1 V_1}{r_1 V_2}(V_2 + V') \text{ hyp.log.} \frac{V_2 + V'}{V_1 + V'} \quad (23)$$

and the area representing the work done by both cylinders per stroke is the sum of (22) and (23), less $P_2 V_2$.

The work per stroke of the low-pressure cylinder is

$$= (23) \times \frac{BD}{CD} - P_2 V_2 \quad . \quad . \quad . \quad (24)$$

and this taken from the work performed by both cylinders per stroke gives the work performed per stroke of the high-pressure cylinder.

The expression (24) becomes

$$\frac{P_1 V_1}{r_1}\left(1 - \frac{V'}{V_2}\right)\left(\frac{V_2}{V_2 - V_1}\right) \text{hyp.log.} \frac{V_2 + V_1}{V_1 + V'} - P_2 V_2$$

in which, if we neglect the last term and make $V' = 0$ we obtain the

Case of no Receiver,

$$\frac{P_1 V_1}{r_1} \frac{V_2}{V_2 - V_1} \text{ hyp. log. } \frac{V_2}{V_1}$$

If we put the ratio of expansion $\frac{V_2}{V_1}$ in the low pressure cylinder $= r_2$ and observe that CL is then the initial pressure in the low-pressure cylinder, which for the moment we may call $P' = \frac{P_1}{r_1}$ the above becomes

$$\frac{P' V_2}{r_2 - 1} \text{ hyp. log. } r_2 = V_2 p'_m \quad . \quad . \quad (25)$$

an expression which is essentially the same as that given just preceding Table C.

Similarly for $V' = 0$ and omitting $P_2 V_2$, the work for the high-pressure cylinder per stroke is

$$\frac{P_1 V_1}{r_1}\left(1 + \text{hyp. log. } r_1 - \frac{1}{r_2 - 1} \text{hyp. log. } r_2\right) \quad (26)$$

and for both cylinders together the work per stroke is

$$\frac{P_1 V_1}{r_1}\left(1 + \text{hyp. log. } r_1 + \text{hyp. log. } r_2\right) \quad . \quad (27)$$

By placing the expressions for the work performed in the two cylinders equal to each other we obtain, after reduction,

$$\text{hyp. log. } r_1 = \frac{r_2 + 1}{r_2 - 1} \text{ hyp. log. } r_2 - 1 \quad . \quad . \quad (28)$$

an expression which gives the value of r_1 the ratio of expansion in the high-pressure cylinder in terms of r_2 the ratio of the volume of the cylinders and also the ratio of expansion in the low-pressure cylinder.

Example:

Placing $r_2 = 3.464$
we get $r_1 = 3.464$

for the only case where the work in one cylinder can equal that in the other, and yet with equal ratios of expansion. But this equality of work fails when there is an appreciable exhaust pressure.

As a 2d example take $r_2 = 2$

Then for equal work performed in the cylinders we have $r_1 = 2.94$

Indeed, equation (28) shows that there are an infinite number of values of r_2 which will satisfy r_1 for equal work performed in the cylinders.

Effect of a Receiver.

As the volume of the receiver is changed from zero to infinity, the point I, Fig. 4, falls from L to the horizontal through N; while the point N remains stationary. To find the point I on a drawing-board for any set of values of

V_1 V_2 and V'; first find N by aid of (13) then draw the adiabatic NI with the proper exponent, and with A for the zero of volumes.

We thus arrive at the important conclusion that by increasing the size of the receiver we diminish the amount of work performed by the same weight of steam, and to the extent due to the corresponding lowering of the line NI.

In the volume V' of receiver must be included all the space about the valves and of the communicating pipes between the cylinders, as well as that in a receiver proper. Thus the superheating chambers sometimes employed between the cylinders must be counted in.

The effect of superheating in the receiver is that to change the pressures and not the volumes. Such superheating simply raises the lines NI and HI. If the steam is dry without a superheater, then with it these lines will be raised nearly in proportion to the elevation of the absolute temperature by superheating.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—September 5th, 1883.

The death of the following named members was announced: Col. F. W. Farquhar, Corps of Engineers, U. S. A., who died July 3, 1883; and Mr. R. J. Brough, of Toronto, Canada, who died July 21, 1883.

The following elections were announced:

As follows: John Lawler, Prairie du Chien, Wis.; Albert Conro, Milwaukee, Wis.; Alex. Mitchell, Milwaukee, Wis.; D. A. Wells, Milwaukee, Wis.; Chas. L. Colby, Milwaukee, Wis.; E. P. Allis, Milwaukee, Wis.; F. de Garay, Mexico.

As members:

Andrew Bell, Carillon, Canada; Henry I. Bliss, La Crosse, Wis.; Wm. W. Card, Pittsburgh, Pa.; Frank C. Doran, Richmond, Ind.; George Downe, Ranwick, Sydney, New South Wales, Australia; Christopher L. Gates, Milwaukee, Wis.; Wm. H. Jennings, Columbus, Ohio; Albon P. Man, Jr., St. Louis, Mo.; Daniel M'Cool, Marquette, Mich.; Wallace M'Grath, Parkersburg, W. Va.; John L. P. O'Hanly, Ottawa, Canada; Geo. W. Polk, San Antonia, Tex.; Watson W. Rich, St. Paul, Minn.; Leonard W. Rundlett, St. Paul, Minn.; Edward H. Williams, Philadelphia, Pa.

As associates:

Joseph P. Card, St. Louis, Mo.; George F. Swain, Boston, Mass.

As juniors:

George B. Francis, Portland, Oregon; Alfred W. Trotter, New York City; Fredk. N. Willson, Princeton, N. J.; Herbert M. Wilson, New York City.

A paper by James L. Randolph, member of the Society, and Chief Engineer Baltimore and Ohio Railroad, upon "Vibration, or the Effect of Passing Trains on Iron Bridges, Masonry, and other Structures," was then read. Mr. Randolph refers to the fact that double track bridges are moved in the direction of passing trains, and are consequently twisted, and strains are produced not provided for. Also that cattle stops and open culverts where built of rubble work have the walls shaken to pieces by vibration.

The remedy he has supplied for these culverts and stops has been to build them of large stone as nearly the same size as possible. The tall, thin bridge piers and abutments on which iron bridges rest have their stone so much disarranged by vibration as to make it necessary to secure them with timber and iron straps. Iron bridges resting on stone pedestals vibrate in this manner and receive a return blow from the vibration of the pedestal, particularly if the pedestal is a light structure, but as the iron and the stone do not vibrate in the same period, there must be times when the result is a movement in the direction of the force. The effect of this vibration has been particularly noticeable at the Harper's Ferry bridge where there was a movement of four inches in four years. After the insertion of planks between the stone and iron this movement ceased. Where the masonry of piers has a platform of timber between its foundation and solid rock, no displacement of stone has been noticed. Mr. Randolph contends that a monolith would be the best support for structures subject to vibration caused by strains, but that a monolith of the specific gravity of granite would give a damaging return blow.

Timber would answer the purpose, but is perishable.

The material which, in his opinion, is most serviceable is an artificial stone which is about two-thirds the weight of granite, is compact, durable, and with very little elasticity.

The paper was discussed by Messrs. Theodore Cooper, Charles E. Emery, H. D. Blunden, and Wm. H. Paine.

ENGINEERING NOTES.

ACCORDING to a correspondent of the *Times* there are now altogether six lighthouses and one light vessel in the Red Sea; four of these are in the Gulf of Suez, and of the remaining three one—that upon the Brother Islets—is not yet lighted. Between the Dædalus Shoal and Perim Island, a distance of more than 800 miles, there is no light at all; and though for 600 miles, after leaving the Dædalus, there are no dangers in the track of steamships, after that the sea is studded with islands and rocks, which render the navigation difficult and dangerous, especially on dark and hazy nights. The places which are more especially dangerous are Jibbel Zukur Island and the Mokha Shoals. On Jibbel Zukur Island there are now the remains of three or four large steamers which have been wrecked there during the last year or two. By placing a lighthouse on Abu Ait Island, three miles to the eastward of the

northern point of Jibbel Zukur, and a light vessel on the Mokha Shoals, the navigation of this most dangerous part of the Red Sea would be rendered much more safe and easy. For homeward-bound ships there is also a great necessity for a light on the south-east end of the Shadwan Island, as a guide to the entrance of the Straits of Jubal. With the great increase of the traffic through the Red Sea which has taken place during the last few years, it is now high time that there should be some improvement in the lighting of this great highway to the East. We may point out that the Canal Company is now extensively adopting Pintsch's fixed and floating gaslights for the canal entrance and elsewhere, and no doubt will soon employ them in the Red Sea, where they are very much wanted.

THE FORTH BRIDGE.—Major-General Hutchinson and Major Marindin have reported to the Board of Trade upon an inspection which they made of the works in progress for the construction of the bridge over the river Forth at Queensferry. After giving details of the progress made with the excavation of the foundations of the viaduct piers, which are on Whinstone rock, the inspectors say:—"The engineers have fornished us with diagrams of the strains upon the piers and other parts of the bridge, showing that, according to the result of their calculations, under no possible combination of a 56lb. wind blowing in any direction, and a rolling load of 3400 tons on the span (*i.e.* two tons to the foot), will the stress either in tension or compression exceed one-fourth of the ultimate resistance of the steel to be used in the construction of the bridge, viz., 30 tons per square inch in tension, and 34 tons in compression. We can report that the preparations which have been made, and the machinery and plant which we are informed have been ordered, indicate that it is the intention of the engineers and contractors to carry out the works in a manner suitable to the magnitude of the undertaking, and that, so far, these works have been completed in accordance with the authorized plans, and in a satisfactory manner."

THE following figures relating to the proposed Messina tunnel have been published:—Length, 13,546.17 meters; fall from Sicily to datum, 154.28 meters; length below the level of the sea on this side, 4688.62 meters; length under the strait, 4299.9 meters; fall from Calabrian side to datum, 153.15 meters; length below level of sea this side, 4565.63 meters; fall of straight parts, 35 in 100, and in curves 32 in 100; cost, 71 million francs.

ORDNANCE AND NAVAL.

TRIALS OF MACHINE AND BREECHLOADING GUNS.—A number of machine and breechloading guns were tried on July 24, at Shoeburyness. The practice commenced with the trial of the improved Gatling gun with the Accles magazine drum. This mode of loading, which precludes the possibility of jamming, enables the gun to fire 104 rounds, or one drum in 2½ seconds. and it has been shown to be possible to fire 10 drums, or 1,040 rounds, in 68 seconds. The invention of these magazine drums is credited to Mr. Accles, of the American Gatling Company. The next gun which was fired at a range of 500 yards, was the single barrel Gardner, many of which have already been issued to the navy. A Nordenfelt 1-inch gun was then fired at 200 yards at a ½-inch wrought iron plate for the purpose of demonstrating its power of penetration. This is a gun with which the navy has also been supplied. The 38-ton 12.5 inch gun then fired Palliser shell, and made excellent practice at a 6-foot 6-inch target at 1,000 yards. Sixteen of these guns have been mounted on board men-of-war. The new 43-ton 12-inch breechloading gun was next tried. This gun, of which two are already mounted on board her Majesty's ship *Conquerer*, it is understood, will with certain slight modifications, in all probability, be distributed to the navy. At present it has obtained a muzzle velocity of 1,770 feet, but with a new powder which is now being made this number will be increased to 2,010 feet. The gun was fired at a range of 1,200 yards, with Palliser shell, at a 6-foot 6-inch target, and made excellent practice. During the day practice with an 8-inch Armstroug breechloading gun on a hydraulic carriage was shown, also a 6-inch breechloading wire gun (Armstrong) fired shrapnel with medium time and percussion fuses at a 6-foot 6-inch target, the range being 2,000 yards. The new Woolwich 9.2 inch breechloading gun was fired, and gave satisfaction. This is an experimental gun, and improvements are expected to be made in it. Its weight is 18 tons, and with a charge of 140 lb. prism powder, it throws a projectile of 380 lb. Its power of penetration of a wrought iron armour plate at 1,000 yards is 15.4 inch, and its muzzle velocity is 1,731 feet. With this gun Captain Goold Adams, R. A., fired a short time since 9 out of 11 shots through a 9-foot target at 2,500 yards. Among the most interesting of the experiments witnessed were those made with the new 6-pounder breechloading quick-firing guns, which have been constructed mainly for the purpose of protecting ships against torpedo-boats. Some ten months ago the authorities invited inventors to construct a 6-pounder gun which should possess a velocity of 1,750 feet, weigh, when mounted, not more than 10 cwt., be capable of firing 11 aimed rounds per minute, require the assistance of only three men to work it, and be also without recoil. At Shoeburyness, on July 24, three such guns, conforming more or less with the conditions laid down, were tried—a Hotchkiss, a Nordenfelt, and an Armstrong gun. The Hotchkiss gun exceeded the weight laid down by the conditions, the Nordenfelt was not free from recoil, and the Armstrong gun did not fulfil the requirements in other particulars. However, when the guns were tried, and it was seen that they were capable of remarkably fine practice, it was felt that, though all the conditions of the Ordnance Committee may not have been fulfilled, yet a great step had been taken towards the solution of the problem presented to the inventors. When the experiments with the quick-firing breechloading guns

had been disposed of, and some practice with a disappearing carriage had been shown, the new 12-pounder breechloading gun, on a hydraulic traveling carriage, fired a number of rounds at ranges varying between 2,000 and 3,000 yards. The practice of this gun, which was placed in soft ground and in a most unfavorable position, was highly satisfactory, and it was understood that it had been accepted as a fact that in it had been found the solution of the field artillery problem. The particulars of this gun are that it is a 12-pounder, its weight seven tons, its charge 4 lb., its projectile 12½ lb., and its muzzle velocity 1,700 feet. The practice with it, as with all those which were tried, was conducted by Captain Goold Adams, who, besides being the inventor of several valuable appliances in connection with his profession, possesses a remarkable skill in the use and manipulation of the various artillery weapons. Some days since, while practicing with the new 12-pounder, he placed nine rounds in succession into a 3-foot 4-inch target at 1,500 yards, which, though it says much for the excellence of the gun, shows also a great proficiency in its management. The practice at Shoeburyness was, on the whole, of the most interesting nature.

THE EIGHTY-ONE-TON GUNS AT DOVER.—The experiments with the two 81-ton guns placed some time since in a turret at the end of the Admiralty Pier, Dover, were successfully made on July 16. There had been some apprehension that the discharging of the gun would be followed by a fall of the cliff, with the probable loss of many lives, and every precaution for the safety of the lives and property of the people of Dover had been taken. For this purpose a general order had been issued and posted up in prominent places throughout the town, stating that the 81-ton guns would be tried on the morning in question, and signifying the signs that were to indicate the moment of discharging. These arrangements were admirably carried out by the Royal Artillery. The previous night, the wind being favorable, blowing strongly from the west off the coast, Colonel Goodenough telegraphed to the Large Ordnance Committee at the War Office inviting them to witness the experiments. A west wind being a favorite trading wind for ships up and down channel, added to the fact that the wind had been blowing for several days from the south, which filled the Downs with shipping, the proposed range was, during the early part of the morning, obstructed by craft going up and down channel. At 10.30 a slight mist came over from the French coast, and the way was thought to be clear. It was well that the artillery officers were not too precipitate in firing the gun, for by the time the loading of one of the guns had been completed, it was seen, the mist having cleared off, that a three-master was right in the line of fire. By the time the range was clear again two hours and a half had elapsed. The loading of one gun, which was only half a full charge of powder, viz., 225 lb., occupied a very few seconds Four men loaded. The rammer being of huge dimensions, took three men to handle it. It was found, however, when all was prepared for discharging, that the men had loaded as they would have, had there been a full charge, that is, with the projectile, that the powder charge had not reached the vent, and that there was a space of at least 6 inches between the powder and the electric igniting wire. This was rectified by further ramming home the charge. At five minutes past one a huge volume of smoke, preceded by a great flash, informed the many thousands that had congregated on the different situations from whence a good view of the proceedings could be had that the greatly feared gun had been discharged. The gun had an elevation of two degrees, and three seconds after being discharged, the projectile, 17 cwt., with which it was loaded, struck and ploughed up the water at a calculated distance of a mile, and, ricocheting, fell again at a short distance. The effect of the discharge was barely felt in the town and neighborhood, although the report was loud and reverberated to an alarming extent off the cliffs. On examination of the gun-carriage gear, it was found that the recoil was indicated as 7 feet, the runners had acted well, and the carriage and aiming apparatus had worked admirably. The succeeding trials were as follows: Second round (fired at 2.10): Charge, 336 lb. of powder; projectile, 17 cwt., elevation, 3 degrees; distance before projectile striking water, four miles; recoil, with greater pressure on the brake than at the preceding discharge, 5 feet. The effect of this shot in the neighborhood was alarming. With a loud crash, one of the large panes in the lighthouse was blown out, and fell within a few feet of the many officers watching the experiment. In expectation of such a mishap, the Trinity House Committee had had a temporary mast erected in close proximity to the lighthouse, whereon a light could be displayed. Third round (2.50 o'clock): Full charge, 450 lb. of powder, projectile, 17 cwt.; elevation, point blank. Projectile struck water half a mile from pier; recoil of gun, 5 feet. The rush of air to the vacuum caused by the tremendous explosion that took place blew out two more of the panes of the lighthouse lantern, the glass of which was over ¼ inch in thickness. The effect in the town and on the cliffs was impressing. No material damages could be seen, but doors and windows rattled, while some of the older houses shook. Fourth round (3.10 o'clock): Charge, 225 lb. of powder; projectile, 17 cwt.; elevation, 3 degrees; recoil, 4 feet. Projectile struck water after traveling four miles; the report had little effect. Fifth and last round (3.30 o'clock): Full charge, 450 lb. powder; projectile, 17 cwt.; direction of gun, lowest possible depression; recoil, 5 feet. Projectile struck water almost immediately after being discharged, 150 yards from the turret, whence it ricocheted out to sea. The report of this discharge was louder than any preceding, and shook to a considerable extent the ground surrounding. No damage was done beyond cracking one of the remaining windows of the lighthouse. Colonel Goodenough and the many officers who had the experiments in hand were perfectly satisfied with the result of the trial.—*Iron.*

IRON AND STEEL NOTES.

CAST-IRON OF UNUSUAL STRENGTH.—By Edward Gridley, Wassaic, N. Y.—Members of the Institute of mining engineers who were present at the Amenia, N. Y., meeting, in October, 1877, will remember their visit to the hematite mines, just west of the village of Amenia, and some of them may perhaps recall the deposit of carbonate ore south of the opening made for the hematite. The smelting of this carbonate during the last few months, has produced an iron that seems worthy of being brought to your notice. A little more than a year ago, at the Wassaic Furnace, Dutchess County, N. Y., we made a few hundred tons of iron from a mixture of two-thirds raw carbonate and one-third Chateaugay ore, hoping that it would be suitable for steel purposes, but as the iron showed phosphorus 0.189 per cent., it was not offered. This iron looked well and seemed quite strong, and gave good results in malleable castings; but no special tests of strength were made.

About February 1st, of this year, we began using two-thirds roasted carbonate, and one-third Chateaugay, and noticing that the iron was stronger than usual, we had two samples tested, which showed tensile strength of 32,014 and 34,176 pounds per square inch, After our stock of Chateaugay ore was exhausted, we put on one-third raw carbonate with the two-thirds of roasted carbonate, and the first test made of the iron, showed 40,008 pounds per square inch.

The three tests given above were made by Mr. A. J. Copp and Mr. E. B. Manning, of the Phœnix Furnace, Millerton, N. Y., on a machine of Riehle Bros., Philadelphia. Since these tests were made, they have broken samples made with all carbonate ore as follows: 39,669, 40,816, 41,882, 42,281, 39,902, and 40,130 pounds per square inch.

A test taken from the same bed of iron as the last-mentioned (40,130), was broken by Mr. A. Blass, at Irondale Furnace, showing 40,151 pounds per square inch. A sample broken on the Riehle Bros. machine, at Stevens Institute, under direction of Professor R. H. Thurston, showed 40,000 pounds per square inch. Another sample was broken by Professor Thurston on his torsion machine, and gave torsion 7°, and tensile strength of 44,500 pounds. And still another sample, broken by Davenport, Fairbairn & Co., Erie, Pa., on their Thurston torsion machine, gave torsion 9°, and tensile strength 47,500 pounds per square inch. The average of the thirteen tests by Fairbanks, is 41,349 pounds.

These tests were all made from iron cast in the pig-bed, direct from the furnace. Some were made from the full pig turned down, but most of them from samples obtained by making a hole in the sand at the end of the pig, from 10 to 20 inches long, and about 1¼ inches in diameter. No tests have yet been made from the re-melted iron.

I add an analysis of the roasted ore, made by Messrs. Booth, Garrett & Blair, February, 1883, and an analysis of the iron, made by Dr. T. M. Drown, May, 1883:

ANALYSIS OF ROASTED CARBONATE.

Silica	8.240	
Peroxide of Iron	77.202	
Alumina	2.768	
Red Oxide of Manganese	3.005	
Lime	1.650	
Magnesia	1.167	
Phosphoric Acid	.275	
Sulphur	.224	
Loss by Ignition	5.684	
Metallic Iron		54.042
Metallic Manganese		2.165
Phosphorus		.120

ANALYSIS OF PIG IRON.

Graphite	2.310	Total, 3.090.
Combined Carbon	.780	
Silicon	1.307	
Sulphur	.086	
Phosphorus	.294	
Manganese	1.512	
Iron	93.700	
	99.989	

IMPROVEMENTS IN WELDING.—The *Mining and Scientific Press* says it seems almost probable that, just at the time when the chief difficulties in the way of welding disappear by reason of our better knowledge and skill in manipulation, the necessity for welding in large masses will be avoided by the use of cast metal. "Heavy hammers, furnaces with neutral or reducing flames, and increased facilities for handling masses of metals, have been making more and more difficult forgings possible, but the introduction of cast steel of almost any desired quality seems to be likely to render forging an art of the past. In smaller masses, like boiler plates, great progress is being made both in this country and abroad. Bottles, buoys, small boiler shelts, fire-boxes, and, in fact, an immense variety of shapes, are now being made out of plate iron without seams or rivets. Very considerable advance is being made in the production of seamless tubes of large size, flat-welded, and cylinders with the head welded together seems to be an unanswered question, the only difficulty being the want of proper plant to manipulate the sheets. Hydraulic welding is making great advances, and some of our large locomotive works are doing very remarkable work in this way. It is notable, however, that in this large work, although an enormous pressure is necessary, the pressure must not be too great, for otherwise the metal which is sufficiently soft to form the weld will be squeezed out and the cooler metal only remain."

BOOK NOTICES.

PRACTICAL TREATISE ON LIGHTNING PROTECTION. By Henry W. Spang. New York: D. Van Nostrand. Price, 75 cents.

This little book affords specific instruction in the method of protecting buildings from lightning. The directions are of the most practical kind and may be safely followed by any builder

whether he is skilled in electrical science or not.

The illustrations are exceedingly well designed to elucidate the text.

LINEAR ALGEBRA. By Hussein Tevfik Pacha. Constantinople: A. H. Boyajian.

We believe that this essay will be read with delight by mathematical students.

The subject is developed so far as to include the equations of the conic sections.

The author is evidently accustomed to imparting instruction, as the presentation of the successive steps is done with much skill.

Linear algebra as treated in this book resembles quaternions, but is much less difficult.

PHILIP REIS, INVENTOR OF THE TELEPHONE. By Silvanus P. Thompson, B. A. London and New York: E. & F. N. Spon. Price, $2.00.

The account of Reis's labors is of special interest just now as the question of the claims of later inventors is being hotly disputed.

The historical part is well prepared, and contains fac-similes of the original pen drawings illustrative of the early instruments.

The appendices which contain documentary evidence of the later inventions of Philip Reis will be regarded by many as of more interest than the history which precedes.

THE NATURALIST'S ASSISTANT. By J. S. Kingsley. Boston: S. E. Cassino. Price $1.50.

This is a valuable aid to young collectors of Zoölogical specimens.

The directions for preserving and for preparing for microscopic work are clear and complete.

The illustrations are only fair.

THE WATCHMAKER'S HAND-BOOK. By Claudius Saunier. London: J. Triplin. Price $5.00.

This is a guide to the artisan, and is of a thoroughly practical character. All the tools of the trade are illustrated by carefully prepared cuts, which are well printed.

A large portion of the book is devoted to the selection, treatment and final finishing of the useful metals, and is thus designed to be serviceable to workers in other trades.

THE FERTILIZATION OF FLOWERS. By Prof. Hermann Muller. Translated and edited by D'Arcy W. Thompson, B. A. London: Macmillan & Co. Price, $5.00.

The interest felt in the subject of this treatise is yearly increasing. Most of the knowledge extant has been accumulated through the researches of a very few workers. The literature of the subject is not extensive.

This work is a record of an enormous mass of original observations. References are made to everything that has been written on the subject of fertilization of flowers by insects.

The illustrations are numerous and excellent.

MISCELLANEOUS.

THE POPULATION OF THE EARTH.—As an authority concerning the population of the different coutries of the world, the publication called "Die Bevolkerung der Erde," published by Justus Perthes, of Gotha, occupies a high position. From the seventh issue of this work, which has recently appeared, we find the total population of the globe estimated at 1,433,887,500, an apparent decrease in the estimate of 1880 of about 22,000,000, while the recent censuses of all the great countries show an increase of over 30,000,000. This is, however, partly explained by a readjustment of the population of China, which, formerly given at 434,626,500, has now been carefully revised and estimated at 371,200,000. After this change of figures for China, Asia is set down as possessing a population of 795,591,000; this includes the 252,000,000 for British India, and the 14,000,000 of the territory of Russia in Asia. The results of recent censuses in Europe show an increase in the population, which is now stated at 327,743,400, as compared with 315,929,000 in 1880—an increase of about 12,000,000. Africa is set down as having a population of 205,823,260; America, 100,415,400, and Australia and Polynesia, 4,232,000. Before some of these vast numbers the total population of the United Kingdom at last census (35,000,000) does not bulk largely, but this is more than counterbalanced by the vast power and influence wielded by our country in every portion of the habitable globe.—*Chamber's Journal.*

THE TEHUANTEPEC SHIP RAILROAD.—Captain Eads states that work has now actually been commenced on the Ship Railway, in the neighborhood of Minatitlan. MM. Van Brocklin is the engineer at present in charge of the work. Assisted by four parties of engineers thoroughly supplied with outfits and instruments, he is now engaged in the task of surveying the proposed route. The first sections near Minatitlan have been approved, and official copies of the surveys filed with the Government in Mexico; and in accordance with the terms of the concession, the Minister of Public Works has detailed one of the most eminent Mexican engineers to be associated in the work. Captain Eads expects that the railway will be completed in less than five years, for the transportation of ships weighing (with their cargoes) 5000 tons gross.

ENGINEERING AND METAL TRADES EXHIBITION.—In order that this exhibition may be made as thoroughly representative as possible of all the branches of trade comprised within its title, and as an encouragement to working men to take a direct part in securing the success of this object, it has been decided to allot free space to such of the working classes as may wish to exhibit inventions or models of their own make. Further it is intended to appoint a committee of manufacturing exhibitors for the purpose of awarding three prizes of ten, five and three guineas respectively to the three most deserving exhibitors in this class. The Exhibition has received the certificate of the Board of Trade which protects unpatented inventions which may be exhibited, and reserves the right to the inventor to apply for a grant of letters patent or provisional protection for six months from the date of opening.

SILICA AND LIME-WATER.—M. Ed. Landrin recently brought before the notice of the French Academy of Sciences some experiments which he has made, proving that silica had the property of absorbing lime-water. Four varieties of silica were employed—hydraulic, gelatinous, Graham's soluble silica, and hydrofluoric acid silica. The process consisted in placing 0.03 grammes of silica in 100 cubic centimeters of lime-water, which had been treated with dilute nitric acid, and after a given time separating the silica charged with lime, and estimating the quantity of lime absorbed. Hydraulic silica absorbs more slowly than Graham's soluble silicate; but the silica of hydrofluoric acid absorbs slowest of all. In all cases the final absorption or saturation is for one equivalent of silica from 36 to 38 of lime. The formula 3 Si O_2 4 CaO, which requires for 30 of silica 37.3 of lime, therefore expresses the limit towards which these puzzuolanic phenomena tend.

ACCUMULATORS AND METALLODION.—Dr. H. Aron, of Berlin, who is well known for his investigations of secondary batteries, has enriched scientific phraseology with the somewhat peculiar term of metallodion, by which he denotes a mixture of any metallic oxide with collodion, the solution of gun-cotton in a mixture of alcohol and ether which is so largely used in photography. Dr. Aron's experiments commenced in the year 1880, when it appears that he, before the proposals of M. Faure became known, used plates consisting of spongy lead, which, however, he found in subsequent experiments suitable only as negative electrodes, the formation of suboxide of lead at the positive electrode probably diminishing the conductivity of the battery. Dr. Aron proposed, it is stated, the use of minium, and once even asked his assistant to prepare a minium plate; he did not carry out the idea, as he considered it impossible to fasten the minium properly to its plate. Later on, however, he prepared a lead plate with a coat of minium and collodion made into a paste, and proceeding on these lines he obtained some interesting results. Metallodion seems to admit of further useful application. If the carbon of a Leclanche cell is brushed over with a paste of pyrolusite and collodion, the carbon rod needs no further adjustment, and may directly be placed with the zinc in the vessel containing the solution of chloride of ammonium without requiring a special porous cell. Dr. Aron further observed that to impart to the lead plate the necessary crystalline structure, it need not be placed in nitric acid previous to its further preparation, it will be sufficient to use a mixture of sulphuric acid with a little nitric acid in the battery, or, better still, to employ at first pure sulphuric acid, and then after the lead has become covered with a thin coating of peroxide, to add the nitric acid, when this peroxide, being practically impenetrable to nitric acid, will prevent any too energetic action. Plates may thus be prepared to the depth of one half millimeter much more quickly than under ordinary circumstances, and they readily acquire a good charge, but they do not appear to be able to hold this charge so long as a Faure or metallodion battery.

THE ELECTROMOTIVE FORCE OF BATTERIES.—Recent experiments by Mr. W. H. Preece, F.R.S., communicated to the Royal Society show that changes of temperature do not practically affect the electromotive force of a battery, but they materially affect the internal resistance. Faraday's observation that the improved current from a heated cell is due to increased conductivity is thus confirmed. Mr. Preece's results also show that of the various forms of batteries in practical use the Daniell is most seriously influenced by variations in temperature, and that in all experiments with that battery either the temperature must be kept constant or frequent measurements should be taken of the internal resistance of the battery and allowance made for the variation. Elaborate curves of variation with temperature in Daniell, bichromate, and Leclanche cells, together with corresponding tables, are given in Mr. Preece's paper. The laborious observations have been made by Mr. Shida. The electromotive forces and resistances of the batteries were measured by the discharge test.

FERRO-PRUSSIATE MULTIPLYING PROCESS.—An improvement has recently been made in this very convenient process for producing copies of drawings in white lines on blue ground by Messrs. Schleicher and Schull, of Duren, Rhenish Prussia. These enterprising paper manufacturers have introduced a continuous transparent drawing parchment in rolls 40 in. wide, and at a very reasonable cost, which is sufficiently transparent to be used in place of the usual tracing, and is still an excellent drawing paper, with a very fine surface, takes pencil and ink well, and will allow lines in pencil to be rubbed out or ink lines to be either scraped out or washed off the surface. It is, moreover, exceedingly tough and well suited for small scale drawings. The instructions for producing blue prints supplied by the above-mentioned firm are as follows: Ammonia citrate of iron 2lb. 5½ oz. avoir., red prussiate of potash 1lb. 9oz. avoir., dissolve separately in water, mix and make the whole up to one gallon, this solution to be carefully kept from light. Ordinary paper upon which the copy is to be produced is then well brushed over with the solution in a dark room and there left to dry. The drawing in transparent parchment or a tracing is then placed in a copying frame with its face to the glass, a piece of ferro-prussiate paper is placed behind and the frame closed, taken out of the dark room and exposed to sunlight. The yellowish green color of the prepared paper changes through bluish green and bluish grey tints into an olive green with metallic reflections; at this stage the process must be interrupted, the frame taken back to the dark room and opened, the drawing washed in cold rain water until the lines are pure white on blue ground, when it can be dried between blotting paper. To be able to watch the progress of the process better, it is advisable to leave the ferro-prussiate paper longer than the frame; the exposure varies with the intensity of the light from five to thirty minutes, the correct time for stopping is soon learned by experience.